NASA CONTRACTOR REPORT

NASA CR-111771

NASA CR-111771

MASTER AGREEMENT TASK ORDER THREE

Design and Fabrication of a Full – Size Landing Impact Test Model of the Mars Legged Lander Configuration

By O.R. Otto, R.A. Melliere, and A. Lopatin

Prepared by
MCDONNELL DOUGLAS ASTRONAUTICS COMPANY-EAST
Saint Louis, Missouri 63166 (314) 232-0232
for Langley Research Center

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION – WASHINGTON, D.C. – SEPTEMBER 197

NASA CR-111771

MASTER AGREEMENT
TASK ORDER THREE

Design and Fabrication of a Full–Size Landing Impact Test Model of the Mars Legged Lander Configuration

By O.R. Otto, R.A. Melliere,
and A. Lopatin

Prepared Under Contract No. NAS 1–8137 by

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY-EAST
Saint Louis, Missouri 63166 (314) 232-0232

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

ABSTRACT

DESIGN AND FABRICATION OF A FULL-SIZE
LANDING IMPACT TEST MODEL OF THE
MARS LEGGED LANDER CONFIGURATION

This report presents a description of the landing impact test model of the Mars legged lander configuration. The model is a full size, variable mass legged lander containing three inverted tripod landing gears to be used for soft landing investigations with either 3/8 prototype mass properties or prototype mass properties. Loading conditions, based on energy absorption characteristics of landing gear and on anticipated landing accelerations, are described. Strength analyses, and minimum margins of safety for all critical parts verifying structural adequacy of model, are presented. Model mass properties are shown to be within specified constraints for both 3/8 prototype mass model and full prototype mass model.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF PAGES

SYMBOLS

A	Area
a, b, h	Cross section dimensions
C G	Center of gravity
D	Diameter
E	Modulus of elasticity
f	Stress
F_A, F_B	A-Frame forces
F_{ALL}	Allowable stress
F_{BR}	Allowable bearing stress
F_C	Allowable compressive stress
F_{CC}	Allowable crippling stress
F_M	Main strut force
F_{RB}	Reference bending stress
F_{SU}	Allowable ultimate shear stress
F_{TU}	Allowable ultimate tensile stress
F_{TY}	Allowable yield tensile stress
Ft.	Feet
g	Acceleration of gravity on earth
I	Moment of inertia
In.	Inch
K , ρ	Radius of gyration
K_{BRU}	Shear - bearing efficiency factor
L'	Effective column length
Lb.	Pounds

SYMBOLS (continued)

M	Applied moment
M_{ALL}	Allowable moment
M.S.	Margin of safety
P	Applied axial load
P_{ALL}	Allowable axial load
P_{BRU}	Allowable lug load in shear-bearing
p, W	Pressure
psi	Pounds per square inch
Q	Static moment of area
R	Radius or resultant footpad force
R_A	Axial load ratio
R_B	Bending load ratio
R_S	Shear load ratio
$R_{X\alpha}$	Parameter used with load interaction curves
S	Applied shear force
S_{ALL}	Allowable shear force
T	Torque
t	Thickness
U_N	Factor of utilization for normal stresses
U_S	Factor of utilization for shear stresses
Wt.	Weight
X, Y, Z	Cartesian coordinates
θ, ϕ	Angles defining landing gear loading cone

SYMBOLS (continued)

μ	Coefficient of friction
η	Limit load factor

1. SUMMARY

This report describes the landing impact test model of the Mars legged lander configuration designed and fabricated by McDonnell Douglas Astronautics Company - Eastern Division under NASA contract NAS 1-8137 (Reference 1). The model is a full size, variable mass legged lander containing three inverted tripod landing gears. Soft landing impact investigations can be conducted using either 3/8 prototype mass properties or prototype mass properties.

Loading conditions were determined using the load-stroke characteristics of the crushable energy absorption material for the landing gear. In addition, loads were based on accelerations anticipated during landing impact tests. A landing dynamics analysis was beyond the scope of this task order.

Strength analyses of all critical parts were performed to insure structural adequacy. Minimum margins of safety are summarized in Figure 1-1.

Because of the importance of mass properties in analytical predictions of landing motions and in correctly interpreting test results, considerable effort was devoted to obtaining representative and reliable estimates of model weight, center of gravity location, and moments of inertia. Predicted mass properties are summarized in Figure 1-2. All masses are within ± 1.25 percent and moments of inertia are within ± 5 percent tolerances specified by NASA Langley Research Center.

MINIMUM MARGINS OF SAFETY

Item	Critical Analysis	M.S.	Ref. Page
Main Strut			
Piston Rod	Column Buckling	+0.13	38
Piston	Plate Bending	+0.10	39
Lug	Bending, Axial Load and Shear	+0.69	40
Clevis Fitting	Bending, Axial Load and Shear	+1.93	41
Footpad			
Radial Beam	Beam Bending	0.00	42
Lug	Bending, Axial Load and Shear	+0.24	43
A-Frame			
Apex Fitting	Bending, Axial Load and Shear	+0.29	45
Tube	Column Buckling	+0.06	47
Lug	Bending, Axial Load and Shear	+0.01	48
Main Strut Support Beam			
Beam	Beam Bending	+0.42	50
Clevis Fitting	Complex Bending, Axial Load and Shear	+0.82	51
Interface			
Beam	Cap Axial Load	+0.10	53
Clevis Fitting	Complex Bending, Axial Load and Shear	+0.08	56
Side Beam	Beam Bending	+0.57	59
Center Section	Beam Bending	+1.72	60

FIGURE 1-1

TEST MODEL MASS PROPERTIES

Model Mass	Property	Predicted Value	Goal	Tolerance %
3/8 Prototype	Weight (Lb)	420	420	0.0
	*CG_X (In.)	25.6	25.6	0.0
	I_{XX} (Slug-Ft^2)	80.4	78.0	+3.08
	I_{YY} (Slug-Ft^2)	50.7	53.0	-4.34
	I_{ZZ} (Slug-Ft^2)	49.6	48.0	+3.33
Prototype	Weight (Lb)	1127.0	1127.0	0.0
	*CG_X (In.)	25.6	25.6	0.0
	I_{XX} (Slug-Ft^2)	215.0	208.0	+3.36
	I_{YY} (Slug-Ft^2)	140.8	142.0	-0.84
	I_{ZZ} (Slug-Ft^2)	123.3	128.0	-3.67

* – Center of Gravity (CG) Measured From Ground Plane

FIGURE 1-2

2. INTRODUCTION

The Mars lander configuration for the Viking mission uses a three legged landing gear to provide soft landing capability and post-landed stability. This gear design combines characteristics of the Surveyor and Apollo Lunar Module landing concepts. Although considerable experience with legged landers of this type has been gained in the lunar landing mission, the increased hazards of the Mars terrain and environment requires extensive testing and evaluation of the proposed landing system concept.

The objective of this task order was to design and fabricate a full size, variable mass legged lander test model of the Mars landing configuration. This model will be used by NASA Langley Research Center to conduct dynamically similar landing investigations. To compensate for the Mars to Earth gravity ratio of 3/8, the model can be tested at 3/8 prototype mass in free body tests or it can be tested with full prototype mass using gravity simulation. Model geometry, mass, and inertia properties for the prototype version are consistent with those of the Viking configuration supplied by the NASA.

3. DISCUSSION

This section contains the structural design criteria, model description, loading conditions and methods of analysis used in the study.

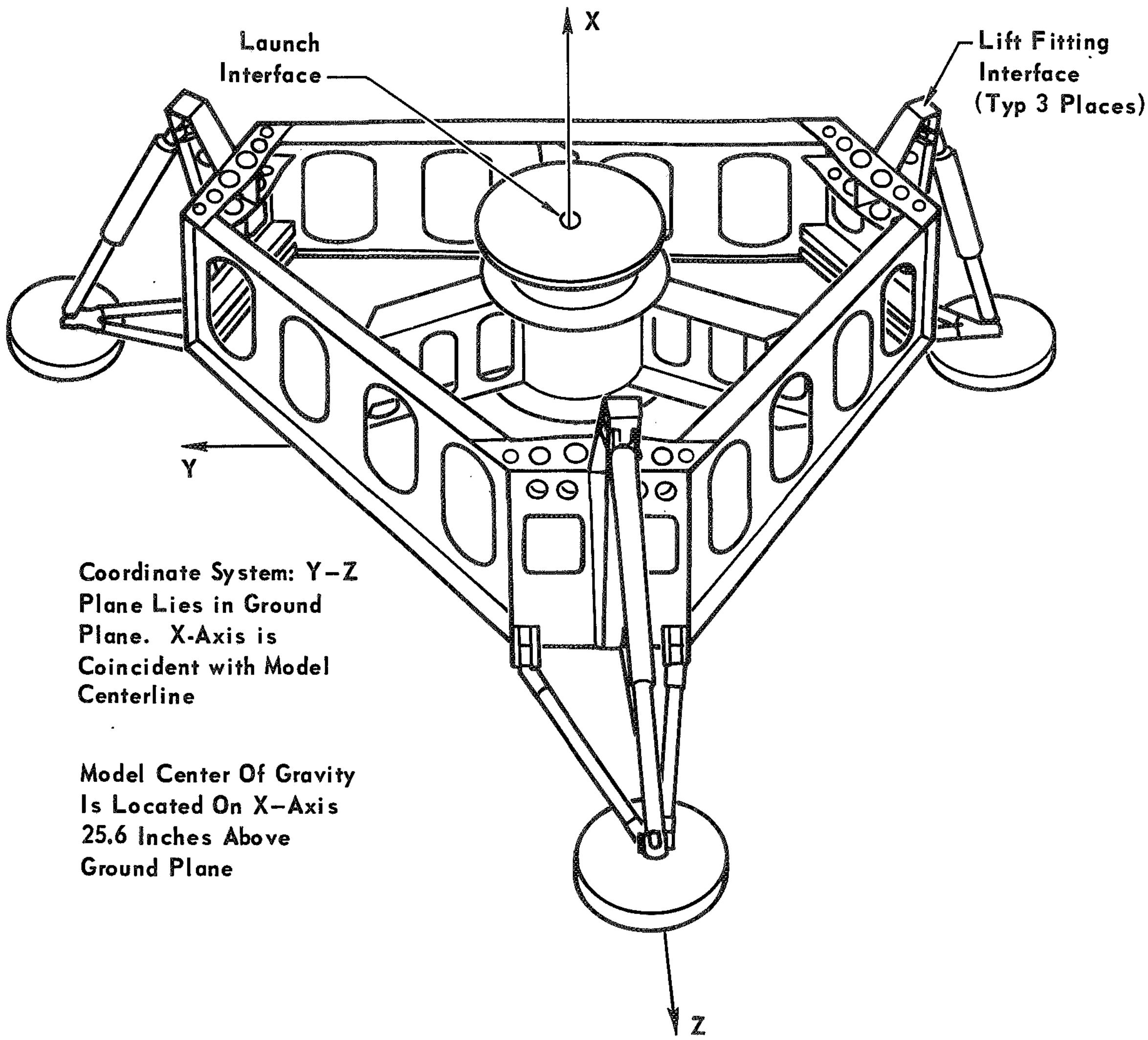
3.1 STRUCTURAL DESIGN CRITERIA - Mass, center of gravity and moments of inertia requirements specified for the model in Reference (2) are defined in Figure 3-1. When the model is ballasted for 3/8 of prototype mass, it will be used for free body testing with initial support occurring at the launch interface. The prototype mass version will be used in gravity simulator testing with initial support provided at the lift fitting interface on each main strut support beam.

All loading conditions for design of the model were based on two constraints: (1) Maximum accelerations expected during landing or hoisting and (2) Load-stroke characteristics of the landing gear main strut and footpad attenuator. The effects of friction forces existing between the footpad and landing surface were considered in determining loads.

Maximum accelerations parallel to the X-axis of the model are 24 g's for the prototype mass version and 64 g's for the 3/8 prototype mass. During hoisting operations for both the free body and gravity simulator tests, accelerations parallel to the X-axis of the model were assumed to be 3 g's.

The structure was designed to preclude failure at ultimate load and to prevent appreciable permanent deformation at limit load. Limit loads experienced during landing were multiplied by a factor of safety of 1.5 to obtain ultimate loads.

MASS PROPERTY REQUIREMENTS



Coordinate System: Y–Z Plane Lies in Ground Plane. X-Axis is Coincident with Model Centerline

Model Center Of Gravity Is Located On X–Axis 25.6 Inches Above Ground Plane

Property	3/8 Prototype Mass (Freebody Tests)	Prototype Mass (Simulator Tests)
Total Model Mass (± 1.25%), Slugs	13 (420 Lb)	35 (1127 Lb)
Landing Gear Mass* (± 10%), Slugs	1.4 (45 Lb)	1.4 (45 Lb)
Model Moment of Inertia (± 5%), Slug-Ft^2		
I_{XX}	78.0	208.0
I_{YY}	53.0	142.0
I_{ZZ}	48.0	128.0

*Does Not Include Interface Clevis Fittings

FIGURE 3–1

3.2 MODEL DESCRIPTION - The lander consists of a welded aluminum center body and machined, high strength aluminum alloy landing gears. Major components are shown in Figures 3-2 and 3-3 and dimensions are given in Figure 3-4. Mass and inertia properties can be varied to permit free body (3/8 prototype mass and inertia) and gravity simulator (full prototype mass and inertia) tests. Ballast is attached to the center body to achieve the required mass properties. The cylindrical part of the center body provides housing for instrumentation.

Each landing gear assembly consists of a machined high strength main strut, A-frame, and footpad. The main strut, shown in Figure 3-5, attenuates landing loads by crushing internal aluminum honeycomb elements. As shown in Figure 3-5, various aluminum alloys are used for the majority of main strut components. Aluminum bronze is used for the piston and ring to provide a low friction bearing surface between sliding components.

The lower A-frame stabilizes the landing gear assembly by carrying any component of applied load on the footpad not parallel to the main strut. The A-frame rotates upward as the main strut strokes. Major components of the A-frame assembly are two 2024-T3 aluminum tubes, two 7075-T651 aluminum lugs, and a 7075-T651 aluminum apex fitting.

A universal connection, allowing two degrees of freedom (rotation) about a point defined by the intersecting center lines of the main strut and A-frame, attaches the 13.25 inch diameter 7079-T651 aluminum footpad to the landing gear. Aluminum honeycomb attached to the footpad assists in the attenuation of landing loads.

FULL PROTOTYPE MASS MODEL

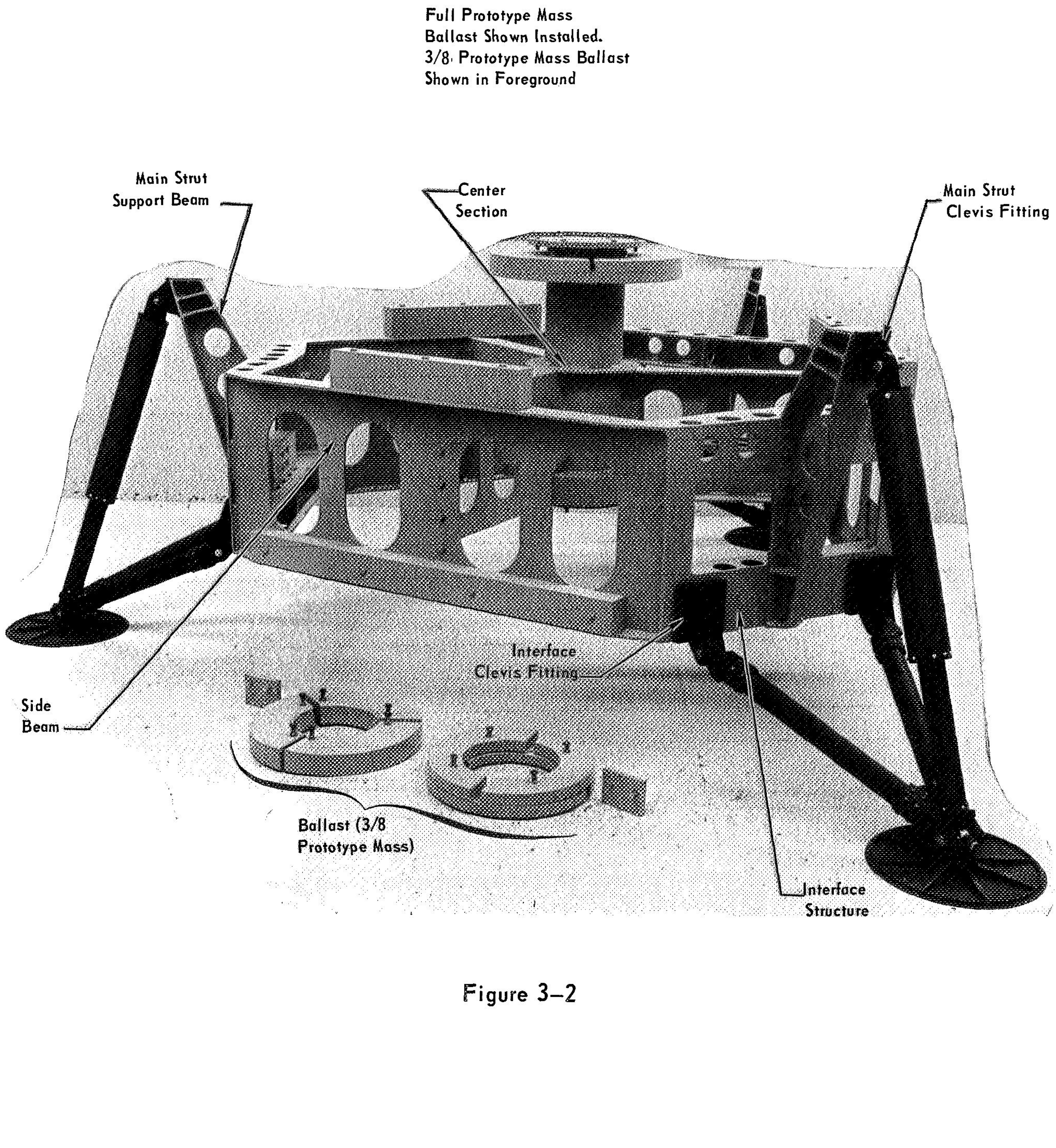


Figure 3–2

LANDING GEAR ASSEMBLY

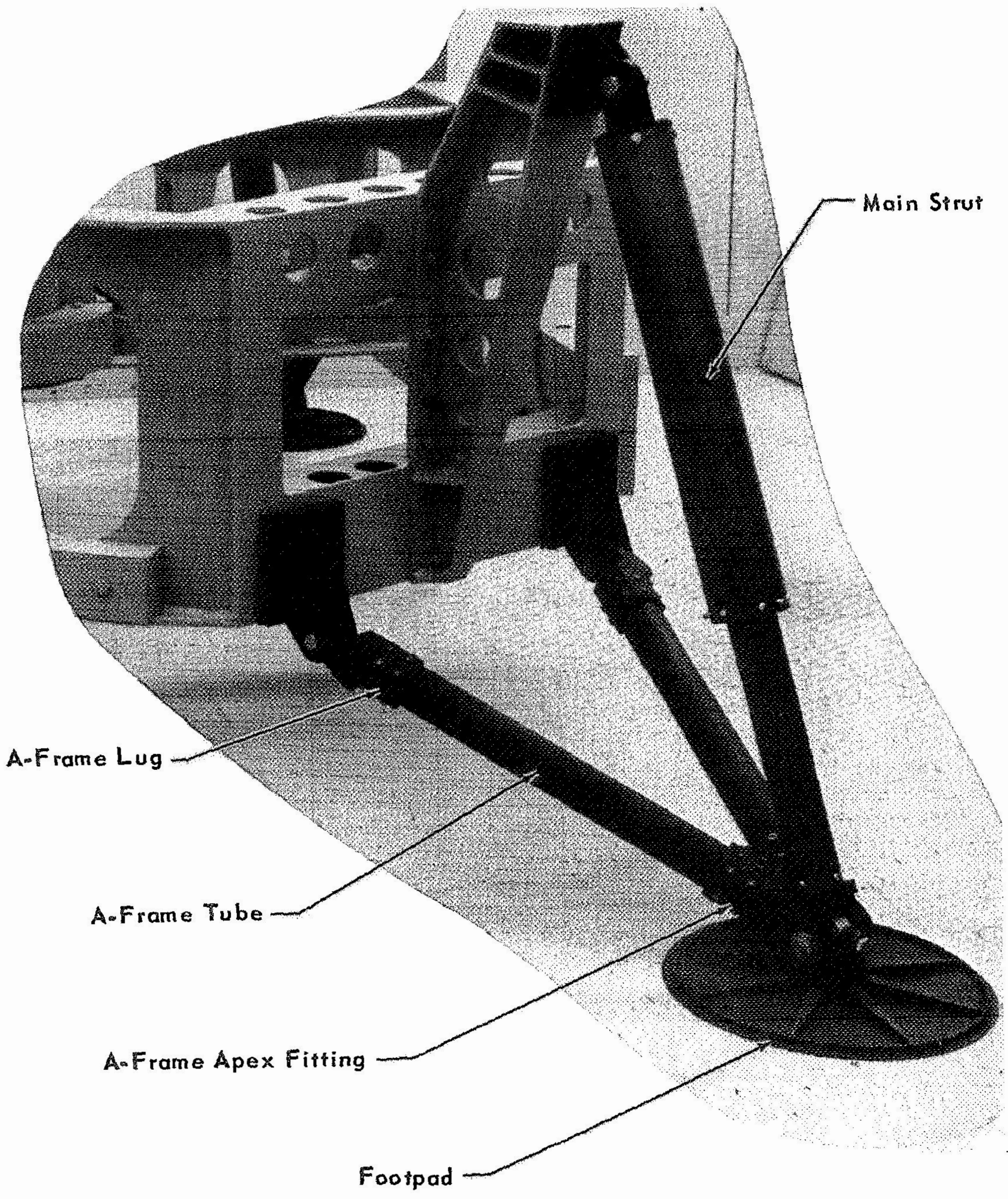


Figure 3–3

LANDER GEOMETRY

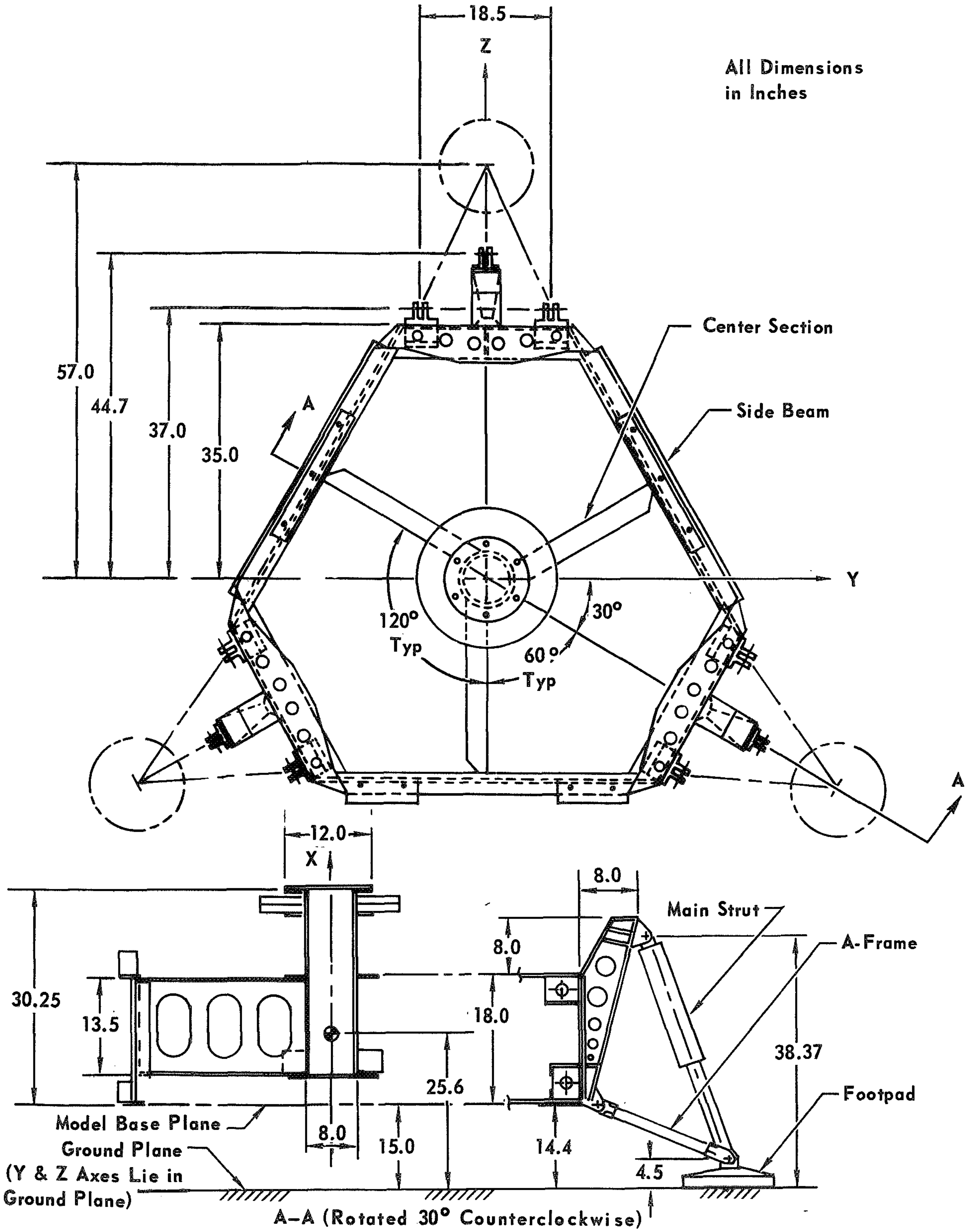


FIGURE 3–4

LANDING GEAR MAIN STRUT

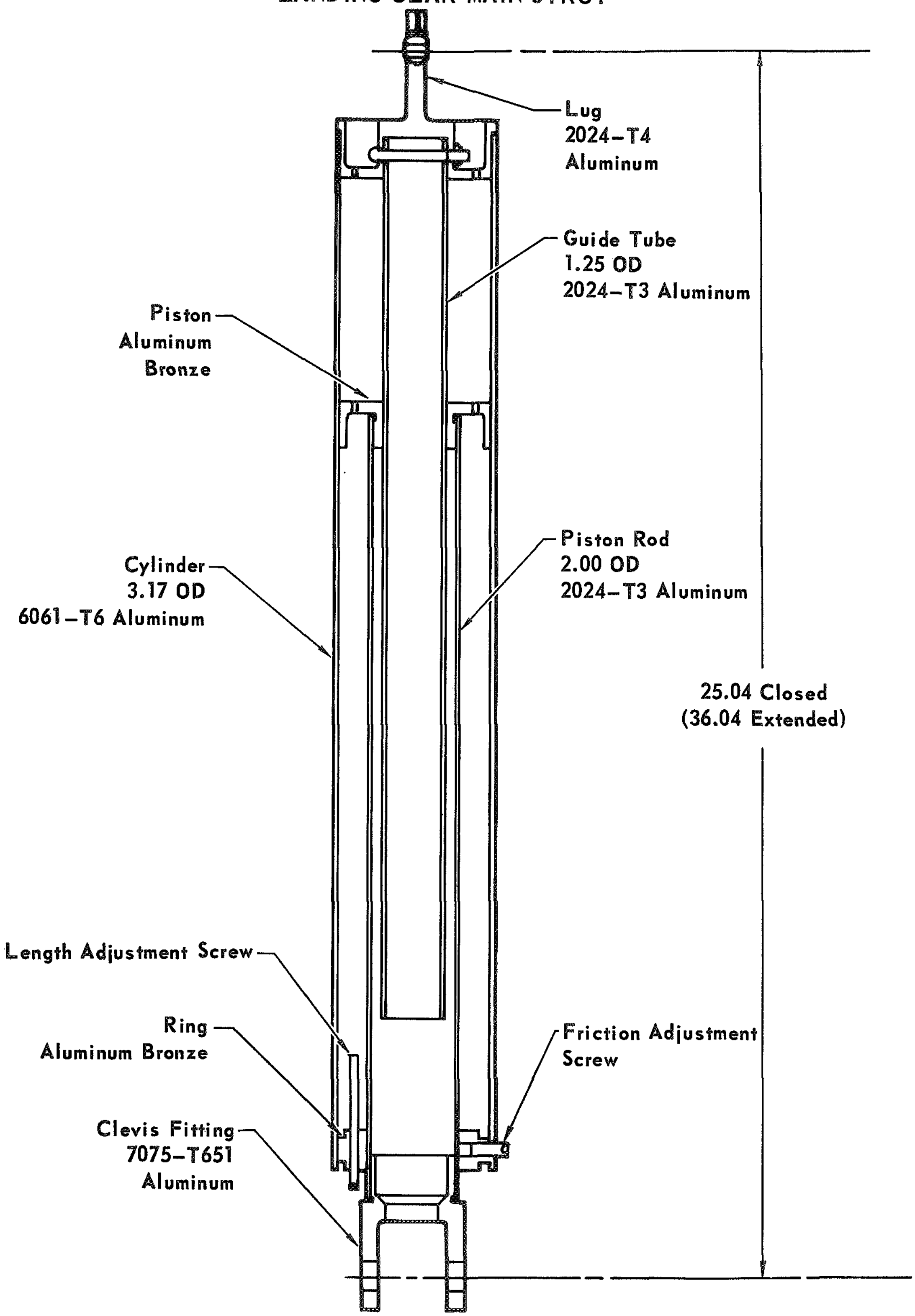


FIGURE 3-5

The center body, which consists of main strut support beams, interface structure, side beams, and center section, is fabricated from 6061-T651 aluminum. The center section is a welded structure made up of an 8.0 inch diameter cylinder and three radial channel-section beams. The cylindrical part provides a flat mounting surface (launch interface) for free body support lugs. The outer portion of the center body is composed of three welded I-beams and interface structure. Interface structure is formed by welding stiffened plates to the ends of center body side I-beams. Main strut support beams and interface clevis fittings are bolted to these interfaces. The main strut support beam provides a mounting surface near the upper end for the clevis fitting used to attach the landing gear main strut to the center body. These beams also provide flat surfaces to attach lift fittings for supporting the model during gravity simulator testing and for hoisting and transporting the model. Machined 2024-T351 aluminum alloy clevis fittings located near the bottom of the interface structure are used to attach the landing gear A-frame to the center body.

3.3 LOADING CONDITIONS - Loading conditions used to design the model were based on anticipated landing accelerations and landing gear attenuation characteristics as discussed in Section 3.1. Based on these constraints, five loading conditions were derived and are summarized in Figure 3-6. Landing gear and center body loads associated with these conditions are defined in Section 4.0..

3.4 METHODS OF ANALYSIS - Standard methods of analysis described in References (3) through (6) were used wherever possible. These methods include

LOADING CONDITIONS

Condition Number	Title	Critical Members	Description
①	Maximum Main Strut Load	Landing Gear Main Strut And Main Strut Support Beam	Determined By Crushing Strength Of Honeycomb In Main Strut.
②	Maximum Footpad Resultant Load	Landing Gear Footpad	Determined By Crushing Strength Of Honeycomb On Footpad
③	Maximum A–Frame Tension Load	Landing Gear A–Frame, Center Body Side Beams And Interface	Combination Of Vertical And Lateral Loads On Footpad That Gives Highest Tension Load On One A–Frame Member
④	Maximum A–Frame Compression Load	Landing Gear A–Frame	Combination Of Vertical And Lateral Loads On Footpad That Gives Highest Compression Load On One A–Frame Member
⑤	Three Leg Impact	Center Body Center Section	Loads Resulting From Three Legs Impacting Simultaneously

FIGURE 3–6

local and general stability analyses of tubular members subjected to axial compression loads, plastic bending analyses of compact sections, interaction of combined stresses, crippling analysis of thin sections loaded in compression, and lug analysis.

Tubular members in the landing gear are critical for axial compression loads. These members are susceptible to both local and general instability modes of failure. Local stability of aluminum alloy tubing was determined using the method presented in Reference (3). In this method, the crippling stress (F_{CC}) for a particular material is defined by the ratio of tube diameter (D) to wall thickness (t). General stability of columns was determined using the Johnson Column formula, Reference (3). This formula is written:

$$F_C = F_{CC} - \frac{F_{CC}^2 (L'/\rho)^2}{4\pi^2 E} \tag{1}$$

This is an empirical equation which includes the effect of interaction between the primary flexural mode of failure and the local crippling mode.

Ultimate strength of bending members is determined using plastic analyses. For bending in the plastic range, the method set forth by Cozzone and described in Reference (4) was used. The allowable plastic bending moment is determined using the following equation:

$$M_{ALL} = (Q_1 + Q_2)\, F_{RB} \tag{2}$$

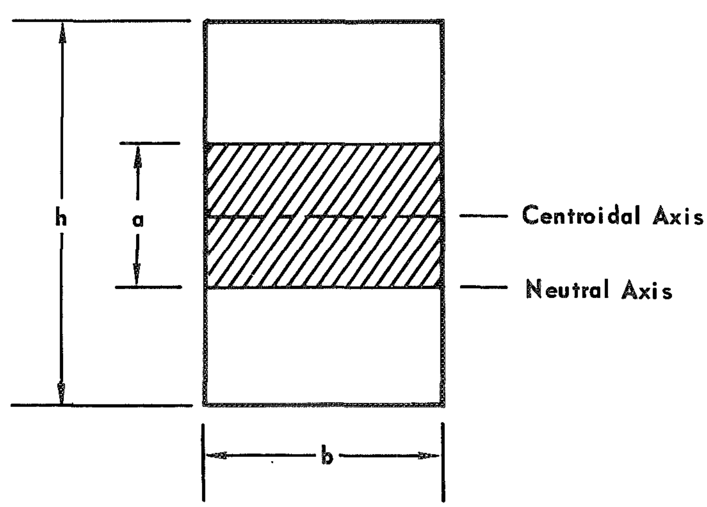
In this equation, Q_1 and Q_2 are the static moments of the area above and below the neutral axis. The reference bending stress, F_{RB}, is a function of material properties and shape of the cross section.

Interaction of combined loads in the plastic range was determined using the methods and curves presented in Reference (3) . Interaction methods most frequently used in the analysis of the model are: combined bending, axial load, and shear; and complex bending, axial load, and shear.

3.4.1 Combined Bending, Axial Load, and Shear - This procedure is a two step operation involving first the interaction of loads resulting in normal stresses on the cross section, and then combining normal stresses with shear stresses. Interaction of bending and axial load on a rectangular section is accomplished using the following interaction equation from Reference (3) .

$$R_A^2 + R_B = 1 \tag{3}$$

Equation (3) is applicable to rectangular sections as evidenced by the following derivation. Consider the section:



Axial load, P , is defined as follows

$$P = F_{ALL}ab \tag{4}$$

The allowable axial load is determined considering no other loads acting.

$$P_{ALL} = F_{ALL}hb \tag{5}$$

Therefore,

$$R_A = \frac{P}{P_{ALL}} = \frac{a}{h} \tag{6}$$

Similarly, bending moment, M , is defined,

$$M = \frac{F_{ALL}b}{4}(h^2 - a^2) \tag{7}$$

The allowable bending moment is determined using equation (2) with no other loads acting.

$$\begin{aligned} M_{ALL} &= \left[\frac{bh^2}{8} + \frac{bh^2}{8}\right] F_{ALL} \\ &= \frac{bh^2}{4} F_{ALL} \end{aligned} \tag{8}$$

Therefore,

$$R_B = \frac{M}{M_{ALL}} = 1 - \frac{a^2}{h^2} \tag{9}$$

Substitution of equation (6) into equation (9) and rearranging terms yields the desired interaction equation.

$$R_A^2 + R_B = 1$$

This equation is plotted in Figure 3-7. The margin of safety for combined loads producing normal stresses without shear is determined by the equation,

$$(M.S.)_{B+A} = \frac{R_{X_a}}{R_B} - 1 \qquad (10)$$

The procedure for obtaining R_{X_a} is shown on Figure 3-7 also.

The second step is to combine loads producing normal stresses with loads producing shear stresses and compute the final margin of safety. The margin of safety for shear loads only on rectangular sections is determined by the equation,

$$(M.S.)_S = \frac{S_{ALL}}{S} - 1 = \frac{F_{SU}\,bh}{S} - 1 \qquad (11)$$

Factors of utilization for loads causing normal stresses and shear stresses are computed by the equations,

$$U_N = \frac{1}{(M.S.)_{B+A} + 1} \qquad (12)$$

$$U_S = \frac{1}{(M.S.)_S + 1} \qquad (13)$$

INTERACTION CURVE FOR COMBINED AXIAL LOAD AND BENDING

RECTANGULAR SECTION

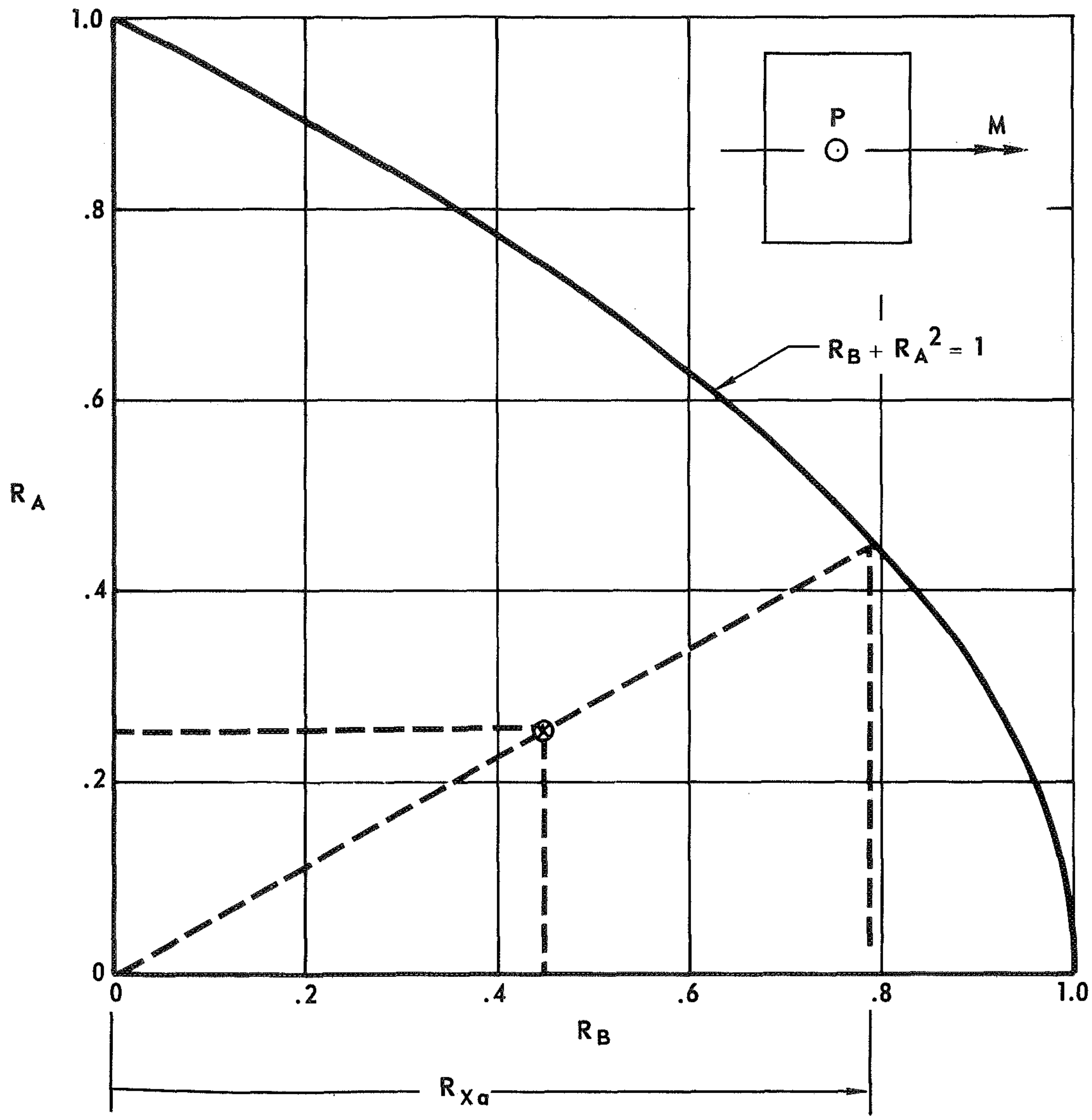


FIGURE 3-7

The final margin of safety when both normal and shear stresses are present is determined by the equation

$$M.S. = \frac{1}{\sqrt{U_S^2 + U_N^2}} - 1 \qquad (14)$$

3.4.2 Complex Bending, Axial Load, and Shear - The procedure for complex bending is very similar to that for simple bending previously described. An interaction curve applicable to rectangular sections shown in Figure 3-8 is used to determine the margin of safety for loads producing normal stresses. This curve was derived in a manner similar to that described for the simple bending case. Ratios R_{BX} and R_{BY} are determined using equation (9) and the ratio R_A is determined using equation (6). The proper interaction curve is selected using the ratio R_A/R_{BX} or R_A/R_{BY}, whichever is smaller. The margin of safety for normal stresses is then determined using procedures described for simple bending. For example, if R_A/R_{BX} is less than R_A/R_{BY}, then the margin of safety for normal stresses is determined by the equation,

$$M.S. = \frac{R_{X_a}}{R_{BX}} - 1 \qquad (15)$$

The ratio R_{X_a} is determined by the procedure shown in Figure 3-8. The remaining calculations to determine final margin of safety when both normal and shear stresses are present, are identical to those for simple bending for which equations (11), (12), (13), and (14) are used.

INTERACTION CURVES FOR COMBINED AXIAL LOAD AND COMPLEX BENDING

RECTANGULAR SECTION

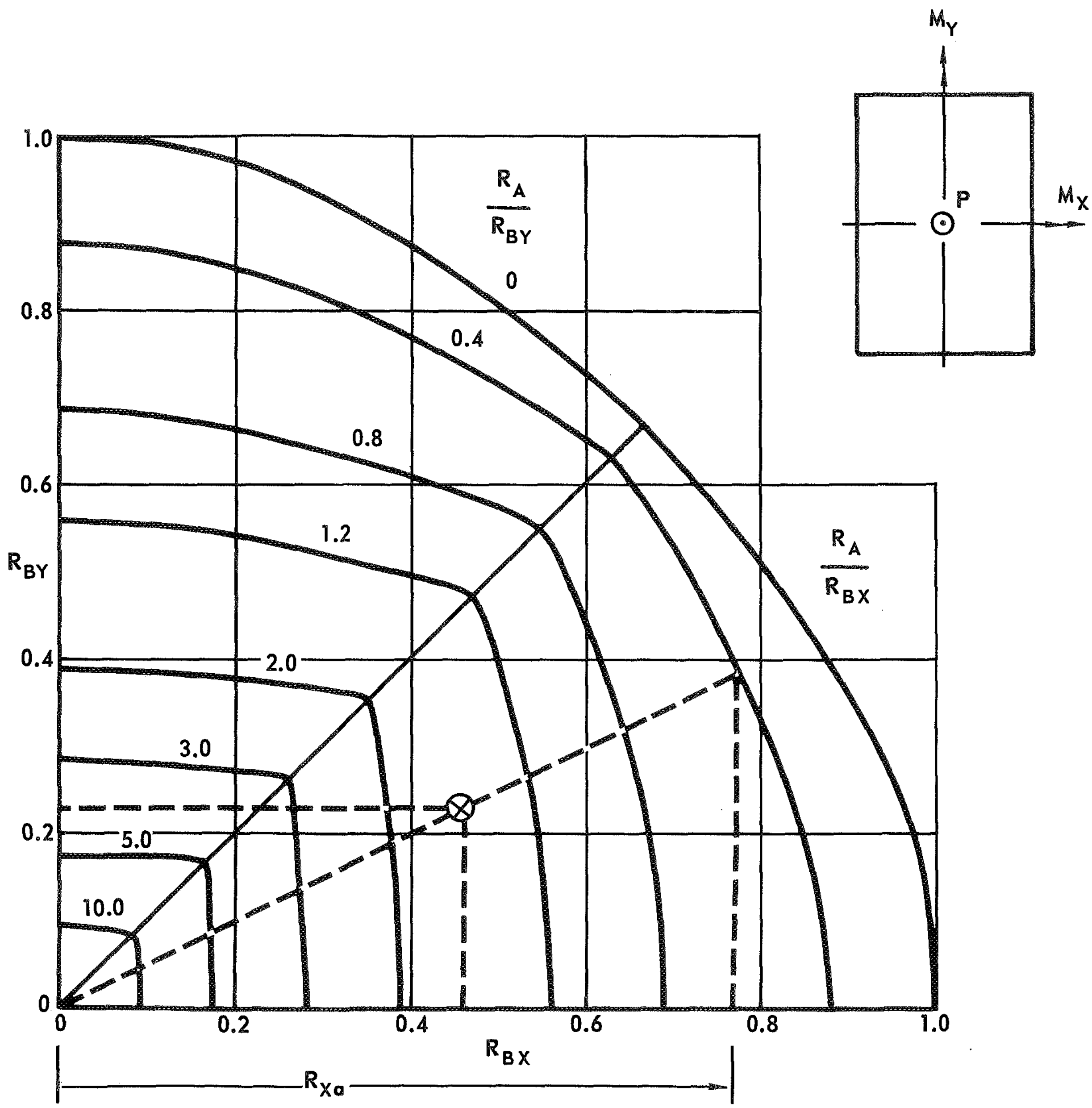


FIGURE 3–8

4. LOADS

Principal external loads applied to the lander are presented in this section. Resultant internal loads are also presented and methods for determining these loads discussed. A detailed landing dynamic loads analysis was beyond the scope of this task order. Conservative assumptions were made throughout the loads analysis to insure the structural integrity of the lander. Landing gear loads were determined by considering forces required to crush the main strut attenuator and the footpad attenuator. Center body loads are based on critical landing gear load conditions and on the assumption that during a flat landing, all three gears stroke to the position resulting in maximum main strut loads. The peak resultant load applied to the lander produces a 24 g acceleration of center body structure.

4.1 LANDING GEAR - Assumptions used in the internal loads analysis of the landing gear are:

- Main strut load-stroke relationship is known.
- Maximum resultant load applied to the footpad is limited to 13,000 lb. by the footpad attenuator.
- Footpad is capable of tilting 25° from the horizontal plane.
- Maximum coefficient of friction between the footpad and landing surface is unity.
- Maximum vertical footpad stroke is 12 inches.

4.1.1 Main Strut - Details of the energy absorbing main strut are shown in Figure 3-5. This strut is designed for the stepped load-stroke relationship shown in Figure 4-1. The stepped load-stroke relationship is

MAIN STRUT LOAD – STROKE RELATIONSHIP

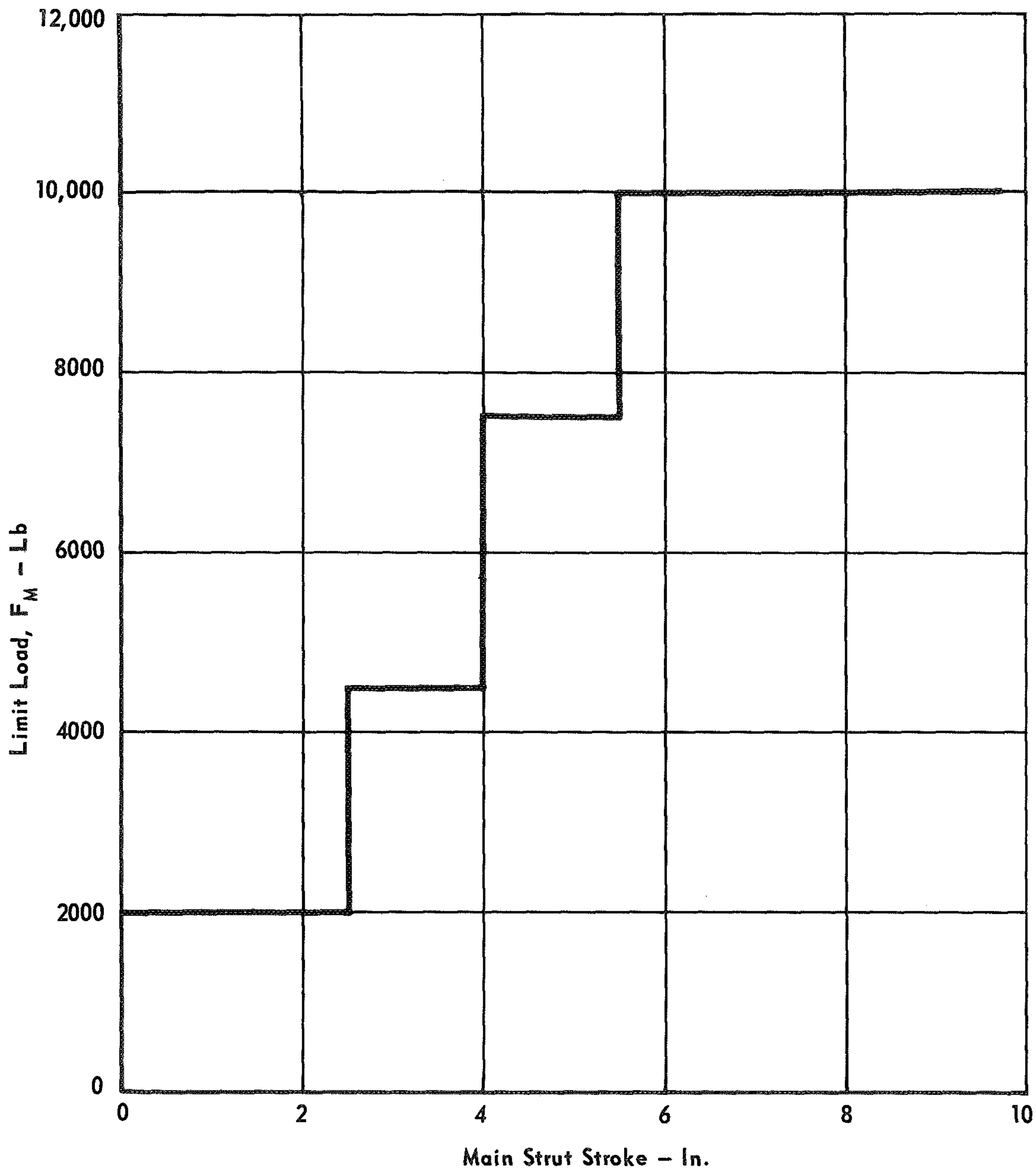


FIGURE 4–1

achieved by stacking "tube-core" type honeycomb elements having various crush strengths and lengths. The maximum limit load of 10,000 lb. occurs at a stroke of 5.50 inches. This load is maintained during the remaining portion of the available stroke. The maximum stroke position of 9.81 inches results in 12.0 inch vertical stroke of the footpad. The maximum stroke position and the associated 10,000 lb. limit load was selected as load condition (1) because this position is critical for the main strut support beam and clevis fitting. Since the main strut is not critical as a column, load condition (1) is also used to design main strut components.

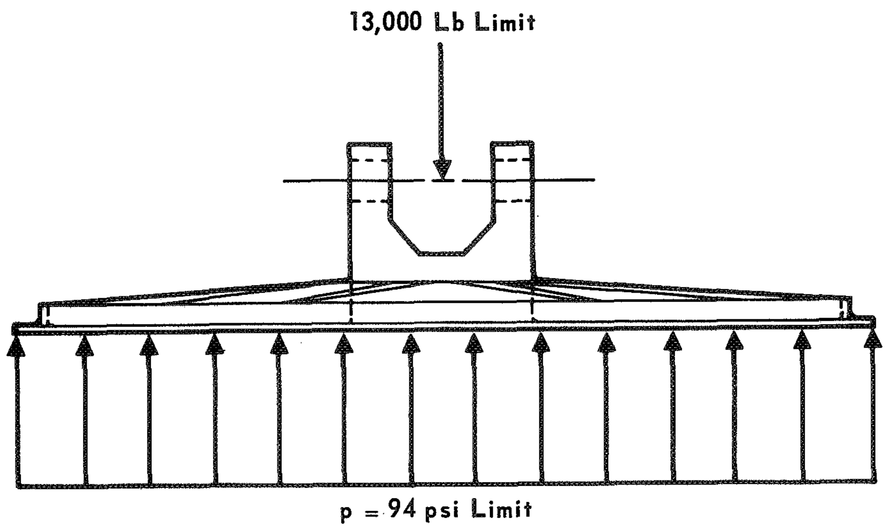
4.1.2 Footpad - A crushable aluminum honeycomb sole is attached to the bottom of the footpad. The honeycomb restricts the maximum resultant limit load on the footpad to 13,000 lb. as defined in Reference (1). This is referred to as loading condition (2) and is illustrated on Figure 4-2. Footpad radial beams are designed for flat landing with a coefficient of friction of zero. This is equivalent to a uniform crush strength of 94 psi on each 13.25 inch diameter footpad. To design the footpad lugs, it was assumed that the 13,000 lb. resultant load acts at a 45 degree angle to the vertical axis of the footpad as shown in Figure 4-2. This load direction is typical of a landing condition when the coefficient of friction is unity.

4.1.3 A-Frame - The A-frame on each gear assembly stabilizes the assembly and rotates upward as the main strut strokes. When the footpad tilt angle of 25 degrees is combined with the friction angle of 45 degrees, the resultant load acting on each gear lies within a 70 degree half cone

CRITICAL LOADS FOR FOOTPAD

Loading Condition (2)

Critical Loads For
Footpad Radial Beams



Assumed Loads For
Design Of Footpad Lugs

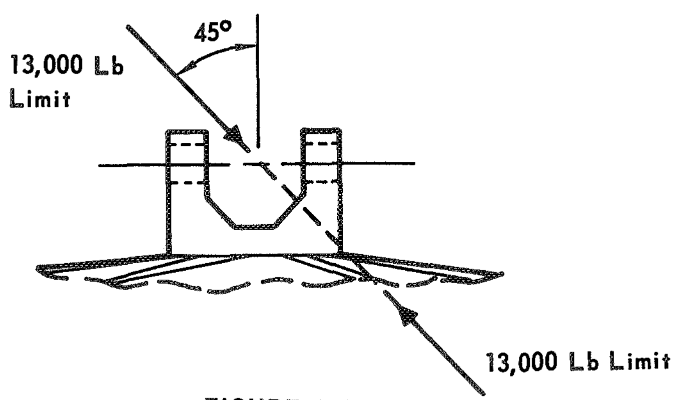


FIGURE 4–2

angle as illustrated in Figure 4-3. The landing gear was assumed massless so that inertia relief was not included in the loads analysis. Loads in A-frame members were determined for several stroked positions and results are summarized in Figure 4-3. For each stroked position, the angles ϕ and θ were systematically varied to determine the largest A-frame tension and compression loads. As an example of this process, landing gear loads for a main strut stroke of 4.7 In. are shown in Figure 4-4. For this stroke, the maximum load the main strut can develop is 7500 Lb. (Figure 4-1), and loads in the A-frame (F_A and F_B) and the resultant load on the footpad (R) are obtained from the equation,

$$\begin{bmatrix} \cos\theta & \ell_1 & m_1 \\ \sin\theta \sin\phi & \ell_2 & m_2 \\ -\sin\theta \cos\phi & \ell_3 & m_3 \end{bmatrix} \begin{Bmatrix} R \\ F_A \\ F_B \end{Bmatrix} = 7500 \begin{Bmatrix} n_1 \\ n_2 \\ n_3 \end{Bmatrix} \qquad (16)$$

In this equation, l_i, m_i, and n_i are the direction cosines of drag struts A and B and the main strut, respectively (i.e. l_1 = cosine of angle between strut A and X-axis). For this example, the angles between the members and the coordinate system axes are:

Member \ Axis	X	Y	Z
Strut A	82.7°	112.3°	156.4°
Strut B	82.7°	67.7°	156.4°
Main Strut	28.6°	90.0°	118.6°

Substituting the cosine of these angles into equation (16) and arbitrarily selecting the angles ϕ = 65 degrees and θ = 70 degrees, yields the following,

$$\begin{bmatrix} 0.3420 & 0.1264 & 0.1264 \\ 0.8516 & -0.3793 & 0.3793 \\ -0.3971 & -0.9166 & -0.9166 \end{bmatrix} \begin{Bmatrix} R \\ F_A \\ F_B \end{Bmatrix} = 7500 \begin{Bmatrix} 0.8782 \\ 0 \\ -0.4783 \end{Bmatrix} \qquad (17)$$

The solution of this equation is,

$$\begin{aligned} R &= 21210 \text{ Lb} \\ F_A &= 21170 \text{ Lb} \\ F_B &= -26450 \text{ Lb} \end{aligned} \qquad (18)$$

A resultant load on the footpad of 21210 Lb. is required to develop the 7500 Lb. main strut load. This footpad load exceeds the 13000 Lb. load permitted by crushing of footpad honeycomb. Therefore, loads in each member are determined from equation (19) where the footpad resultant load is limited to 13000 Lb.

$$\begin{bmatrix} \ell_1 & -n_1 & m_1 \\ \ell_2 & -n_2 & m_2 \\ \ell_3 & -n_3 & m_3 \end{bmatrix} \begin{Bmatrix} F_A \\ F_M \\ F_B \end{Bmatrix} = 13000 \begin{Bmatrix} -\text{COS}\theta \\ -\text{SIN}\theta \ \text{SIN}\,\phi \\ \text{SIN}\,\theta \ \text{COS}\phi \end{Bmatrix} \qquad (19)$$

Substituting values as previously described yields,

$$\begin{bmatrix} 0.1264 & -0.8782 & 0.1264 \\ -0.3793 & 0 & 0.3793 \\ -0.9166 & 0.4783 & -0.9166 \end{bmatrix} \begin{Bmatrix} F_A \\ F_M \\ F_B \end{Bmatrix} = 13000 \begin{Bmatrix} -0.3420 \\ -0.8516 \\ 0.3971 \end{Bmatrix} \qquad (20)$$

The solution of equation (20) is,

$$\begin{aligned} F_A &= 13000 \text{ Lb} \\ F_M &= 4600 \text{ Lb} \\ F_B &= -16200 \text{ Lb} \end{aligned} \qquad (21)$$

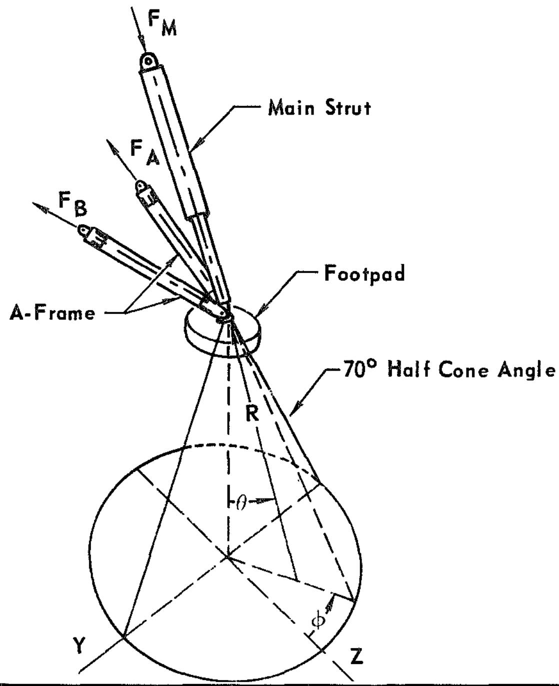
These loads correspond to points on curves in Figure 4-4 denoted by triangles (Δ). Other points on these curves were similarly obtained by varying only the angles ϕ and θ. The angles ϕ = 65 degrees and θ = 70 degrees result in the largest A-frame compression load when the main strut stroke is 4.7 In. Similarly, the angles ϕ = 107 degrees and θ = 65 degrees result in the largest A-frame tension load. Member loads for this condition are identified by circles (○) in Figure 4-4.

Other stroke positions, including those corresponding to steps in the main strut load stroke curve, were analyzed in a similar manner. For each position, the angles ϕ and θ were determined which produced the largest A-frame compression and tension loads. These angles, and the associated member loads, are summarized in Figure 4-3. As indicated in the figure, A-frame tension and compression conditions are not necessarily defined by the same values for angles ϕ and θ. The maximum A-frame tension load occurs for a main strut stroke of 4.7 In. and is denoted as loading condition ③. The maximum A-frame compression load occurs at the onset of stroking and is labeled loading condition ④.

An envelope of A-frame tension and compression loads as a function of main strut stroke is shown in Figure 4-5. The tension and compression loads for loading conditions ③ and ④ are noted.

4.2 CENTER BODY - Design loads for the center body structure are presented in this section. Main strut support beam and interface structure were designed for loading conditions defined earlier. Several assumptions were necessary to determine design loads for the side beams and center section because a landing dynamic analysis was not performed. Side beam design loads were determined on the basis that conditions causing critical loads for the design of the landing gear can occur on two gears simultaneously. Center section design loads were obtained by assuming the landing gear strokes to the maximum load position during a flat landing. Internal loads analysis

LANDING GEAR LOADS AND GEOMETRY DEFINING A-FRAME TENSION AND COMPRESSION CONDITIONS



(1) Footpad Stroke – In.		0	3.00	3.35⁻	3.35⁺	5.10⁻	5.10⁺	6.00	7.00⁻	7.00⁺	9.00	12.00
(1) Main Strut Stroke – In.		0	2.32	2.50⁻	2.50⁺	4.00⁻	4.00⁺	4.70	5.50⁻	5.50⁺	7.17	9.81
A-Frame Tension Condition	(2) R	13000	6800	6100	13000	10440	13000	(3) 13000	13000	13000	13000	13000
	F_A	10400	6600	6400	14400	14200	19000	19500	18900	18900	18900	18500
	F_M	2000	2000	2000	4500	4500	6900	7300	6070	6070	5230	4000
	F_B	-17800	- 8600	-7800	-16425	-11970	- 8830	-10700	- 9000	- 9000	- 9180	- 9370
	θ	70	70	70	70	70	70	65	70	70	70	70
	ϕ	58	65	70	73	90	120	107	120	120	120	120
A-Frame Compression Condition	R	(5) 13000	13000	13000	13000	13000	13000	(4) 13000	13000	13000	13000	13000
	F_A	10400	3800	1800	14400	13275	14000	13000	11900	11900	14391	14700
	F_M	2000	2000	2000	4500	4500	4600	4600	4700	4700	5231	5500
	F_B	-17800	-14500	-13000	-16425	-16650	-16500	-16200	-16000	-16000	-15928	-15900
	θ	70	70	70	70	70	70	70	70	70	70	70
	ϕ	58	34	27	73	67	70	65	60	60	70	70

Notes:

(1) Superscripts (– and +) on Stroke Position Indicate a Step In The Main Strut Load–Stroke Relationship.

(2) All Loads Are Limit (Lb.). All Angles Are In Degrees.

(3) A-Frame Tension Condition For a 4.7 In. Main Strut Stroke. Loads Identified By Circles (O) In Figure 4–4. This Condition Is Also The Maximum A-Frame Tension Condition – Loading Condition ③

(4) A-Frame Compression Condition For a 4.7 In. Main Strut Stroke. Loads Identified By Triangles (Δ) In Figure 4–4.

(5) Maximum A-Frame Compression Condition – Loading Conaition ④

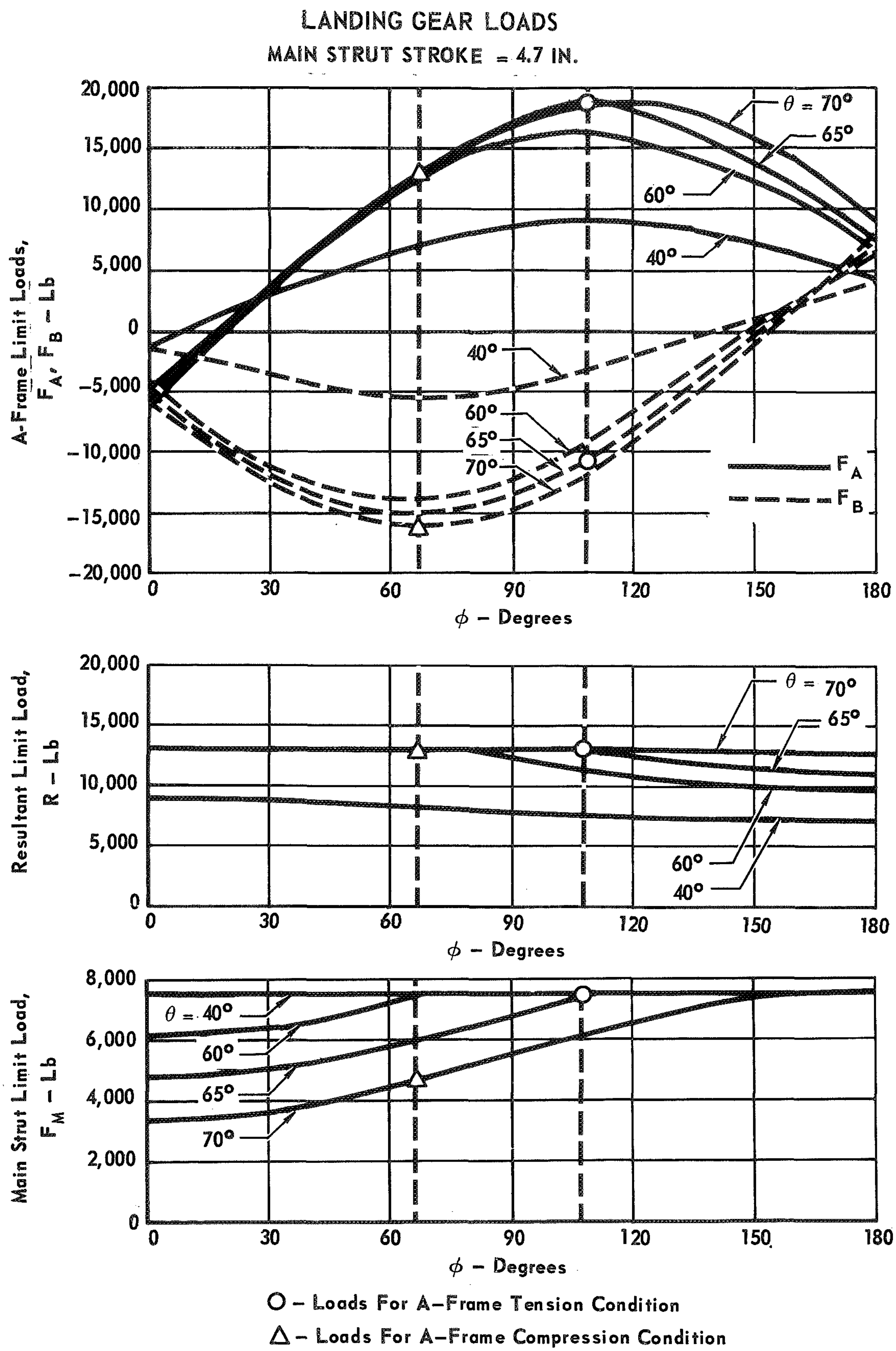
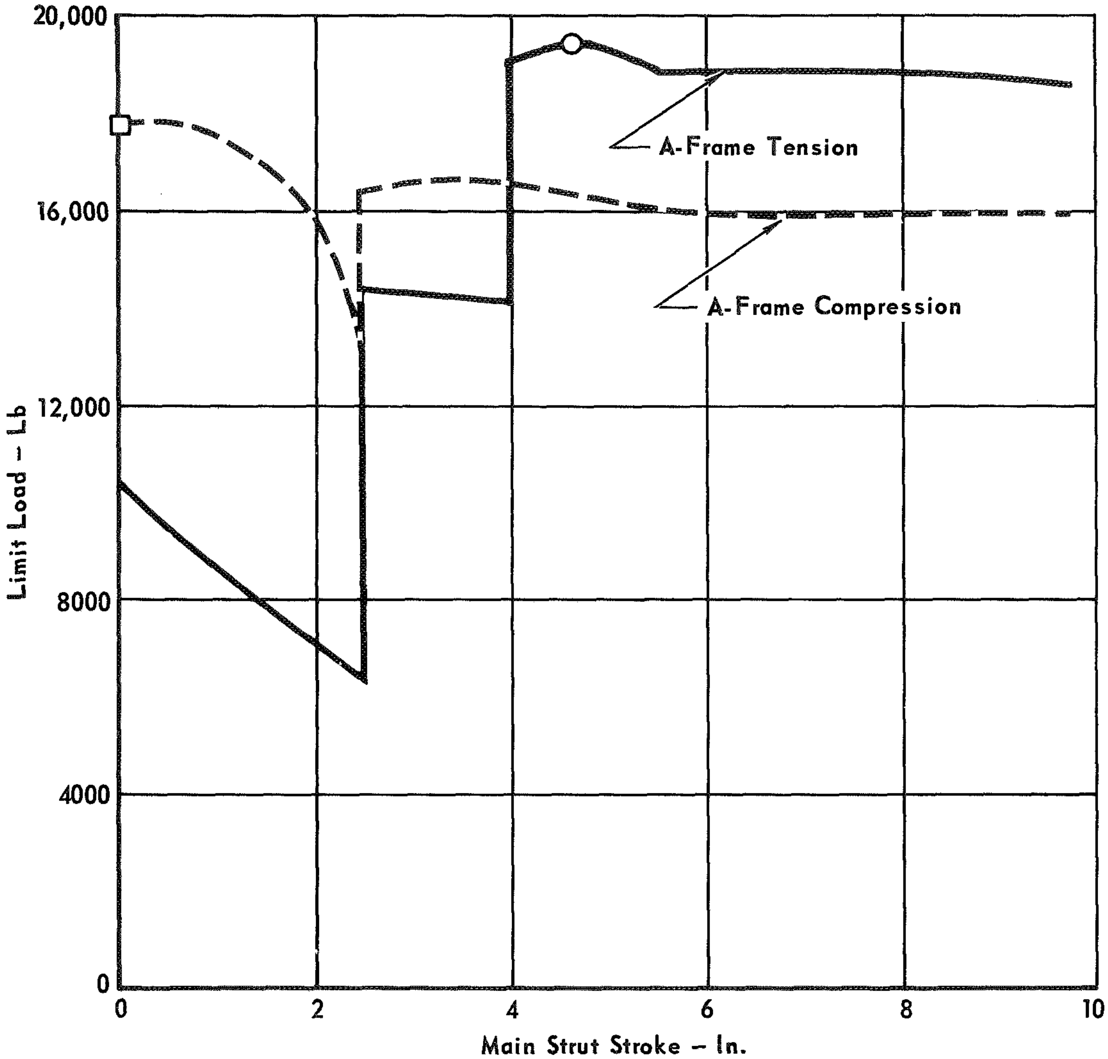

LANDING GEAR LOADS
MAIN STRUT STROKE = 4.7 IN.
A-Frame Limit Loads, F_A, F_B – Lb
20,000
15,000
10,000
5,000
0
–5,000
–10,000
–15,000
–20,000
θ = 70°
65°
60°
40°
F_A
F_B
φ – Degrees
0
30
60
90
120
150
180
Resultant Limit Load, R – Lb
Main Strut Limit Load, F_M – Lb
8,000
6,000
4,000
2,000
θ = 40°
O – Loads For A–Frame Tension Condition
Δ – Loads For A–Frame Compression Condition

FIGURE 4–4

ENVELOPE OF A-FRAME LOADS



○ – A-Frame Tension Load For Maximum Tension Condition (Loading Condition ③)

□ – A-Frame Compression Load For Maximum Compression Condition (Loading Condition ④)

FIGURE 4–5

of the center body was based on the assumption that inertia loads resulting from structural members and ballast are idealized as point loads.

4.2.1 Main Strut Support Beam - The main strut support beam was designed to react the maximum load occuring in the main strut. External loads applied to this beam are shown in Figure 4-6. These loads result from loading condition (1) defined in Section 4.1.1.

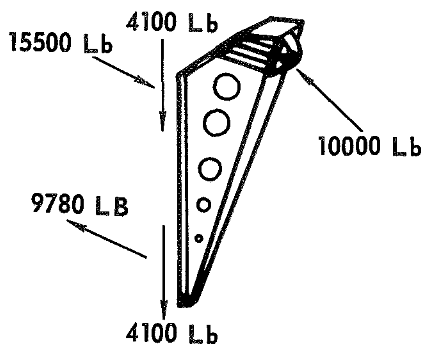
4.2.2 Interface - Interface structure is designed for loads resulting from loading condition (3), the maximum A-frame tension condition. External loads applied to the landing gear, interface and a side beam are shown in Figure 4-7 for this condition.

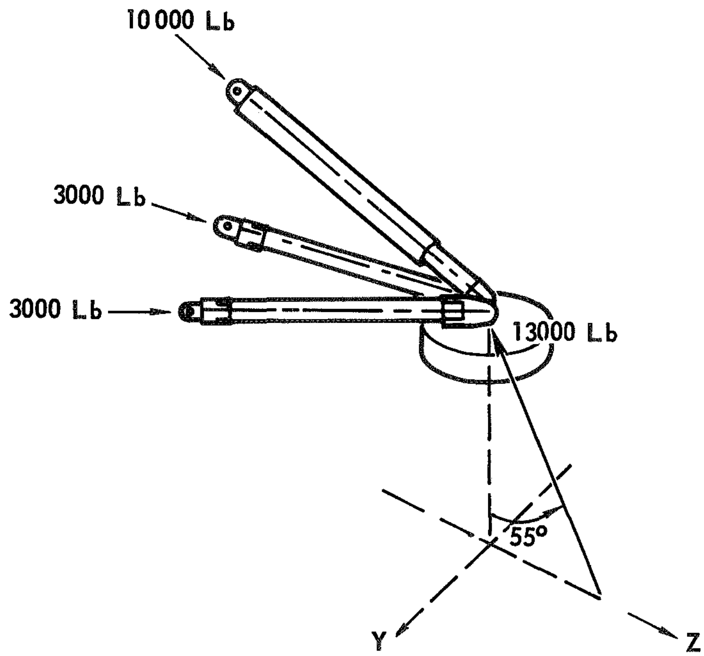
4.2.3 Side Beams - A number of conditions were investigated to determine maximum loads on the side beams. The critical condition was found to result from the maximum A-frame tension condition. Maximum loads applied to the side beams are shown in Figure 4-7. These loads were assumed to be applied to each end of a side beam as shown in Figure 4-8. This would be the case for a two gear landing. These loads are conservative since they result from footpad and main strut attenuator crushing while inertia relief of the landing gear and interface structure was ignored.

4.2.4 Center Section - Design loads for the center section result from accelerations occurring during flat landing on three gears. Total load on the lander as a function of stroke for flat landing is shown in Figure 4-9. Results are shown for coefficients of friction of 0, 0.5 and 1.0. Maximum load occurs for a main strut stroke of 5.5 inches with a coefficient of friction of 1.0. This results in a maximum landing load factor of 24 g's. This condition, used to design the center section beams, is referred to as loading condition (5) and illustrated in Figure 4-10.

CRITICAL LOADS FOR MAIN STRUT AND MAIN STRUT SUPPORT BEAM

Loading Condition (1)
Main Strut Fully Stroked





All Loads Are Limit

FIGURE 4–6

MAXIMUM A-FRAME TENSION LOAD DISTRIBUTION

Loading Condition (3)

Limit Loads Shown

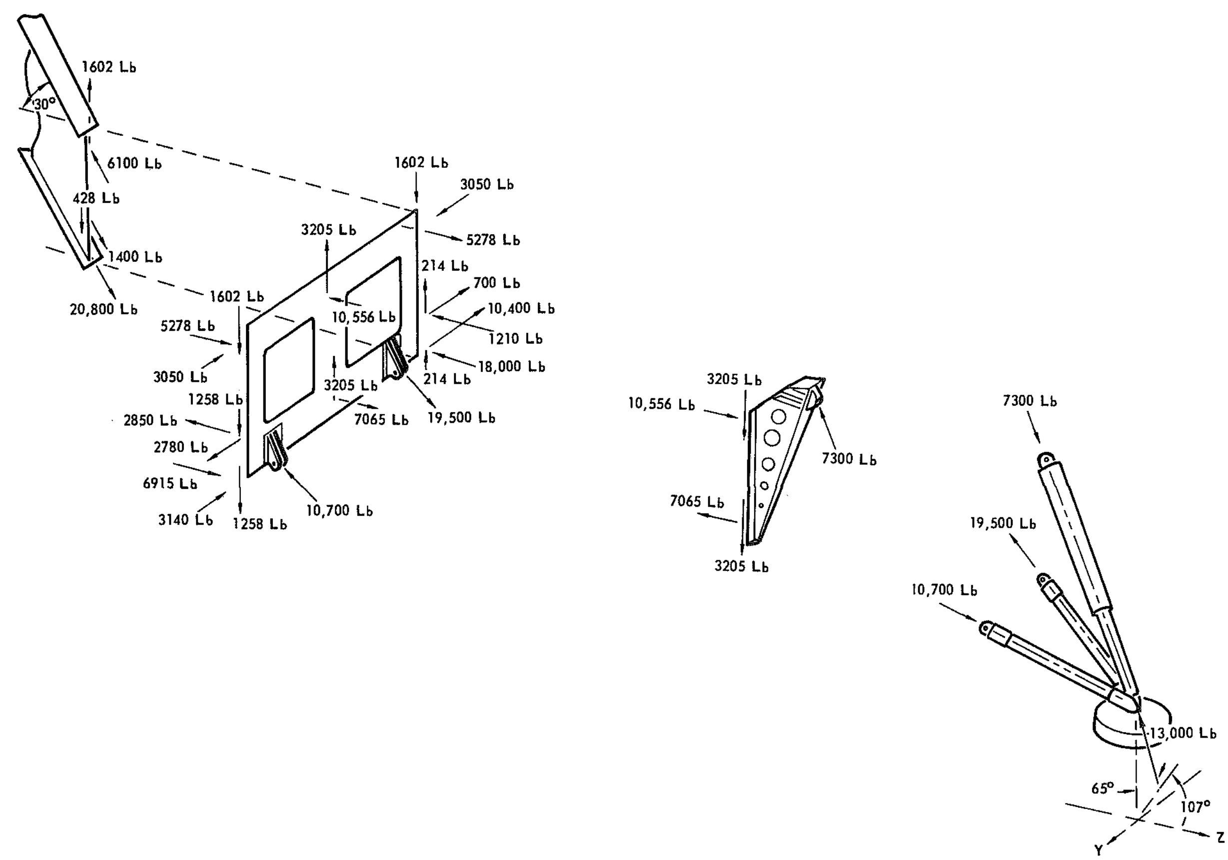


FIGURE 4–7

CRITICAL LOADS FOR CENTER BODY SIDE BEAMS

Loading Condition (3)

Interface Loads From Condition (3)
Assumed Applied At Each End Of Beam.
Inertia Loads Assumed Concentrated
At Center Of Side Beam

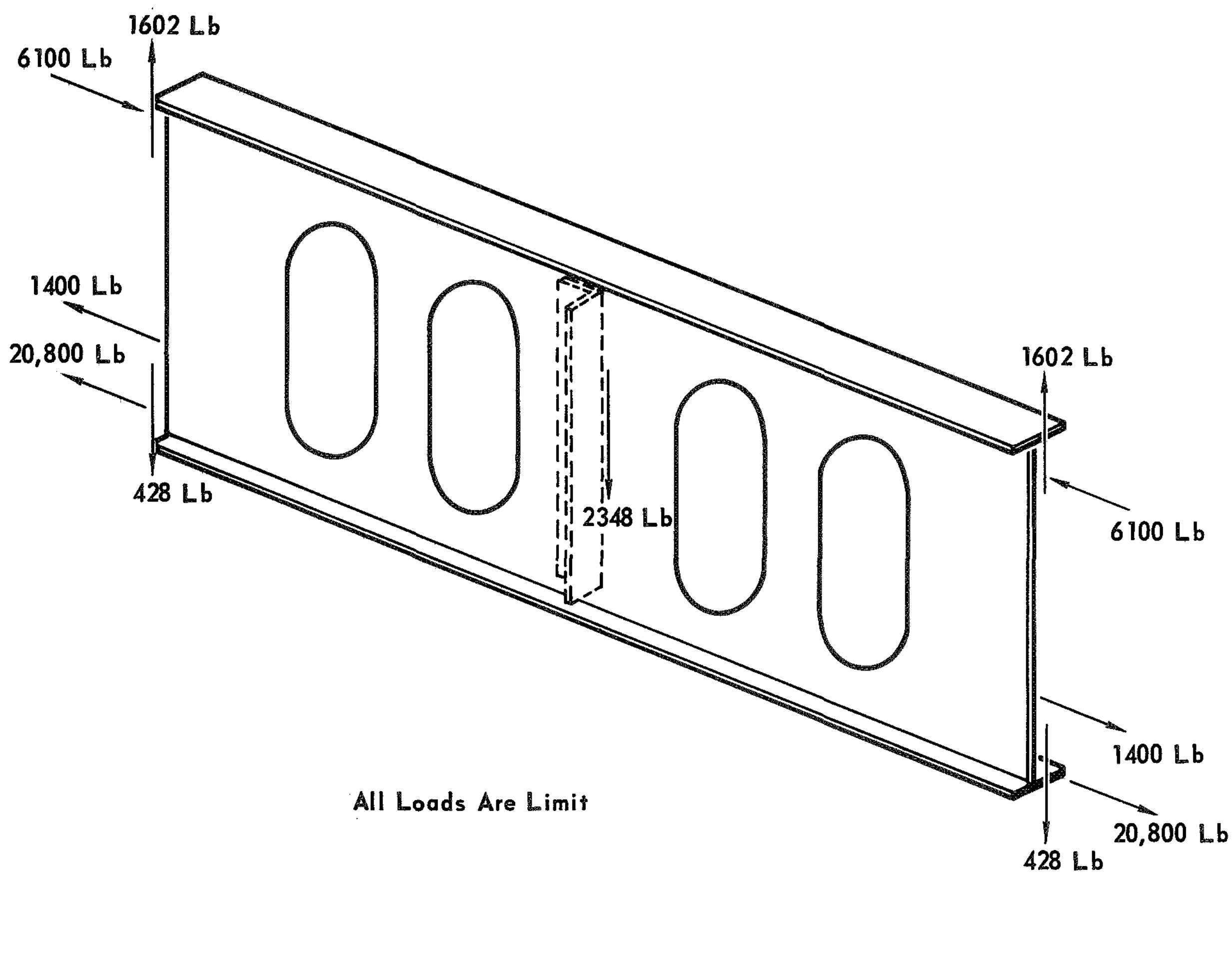


FIGURE 4-8

FLAT LANDING LOADS

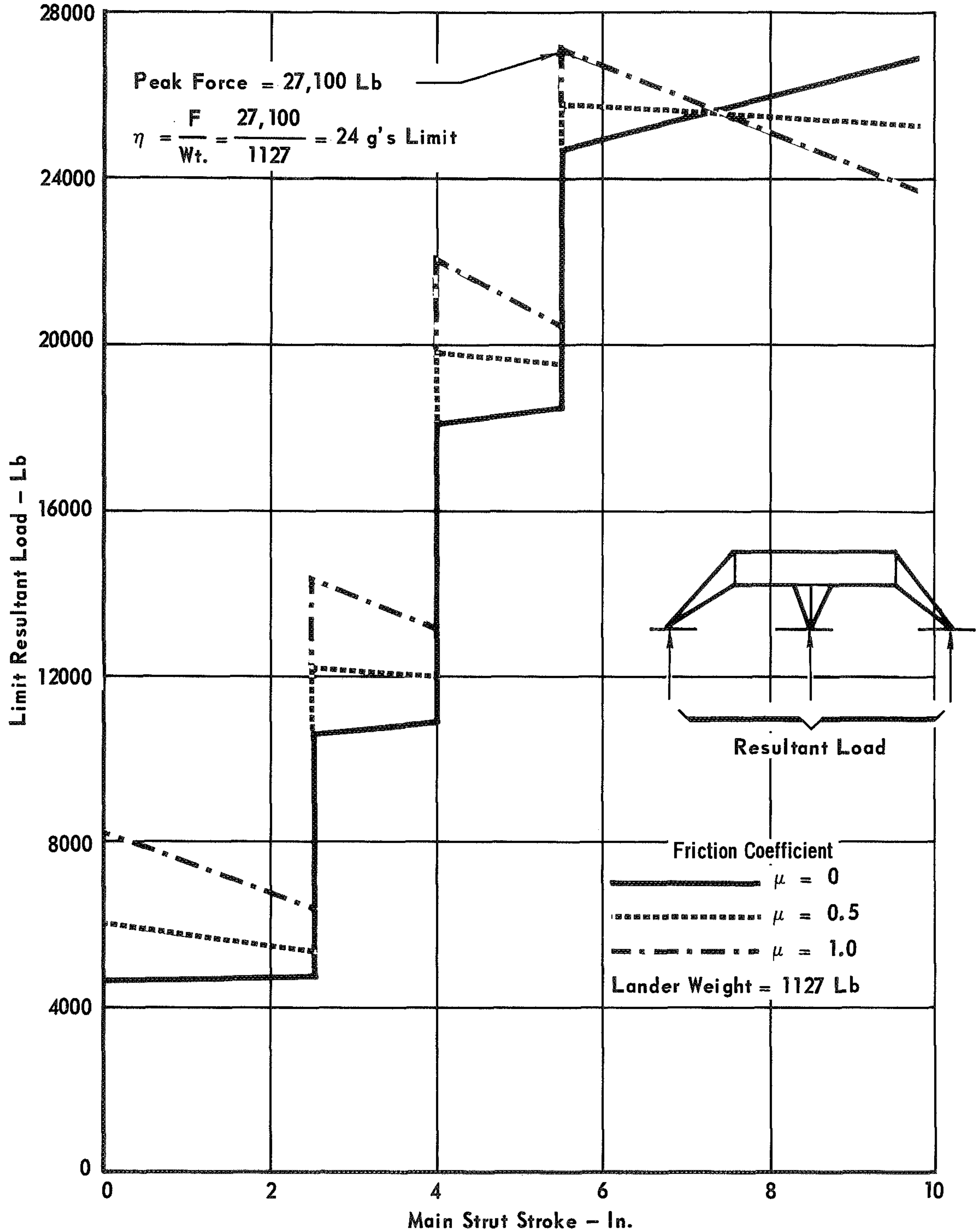


FIGURE 4–9

CRITICAL LOADS FOR CENTER SECTION

Loading Condition (5)

Center Section Structural Weight = 50.9
Full Prototype Mass–Ballast Weight = 218.1
Total 269 Lb

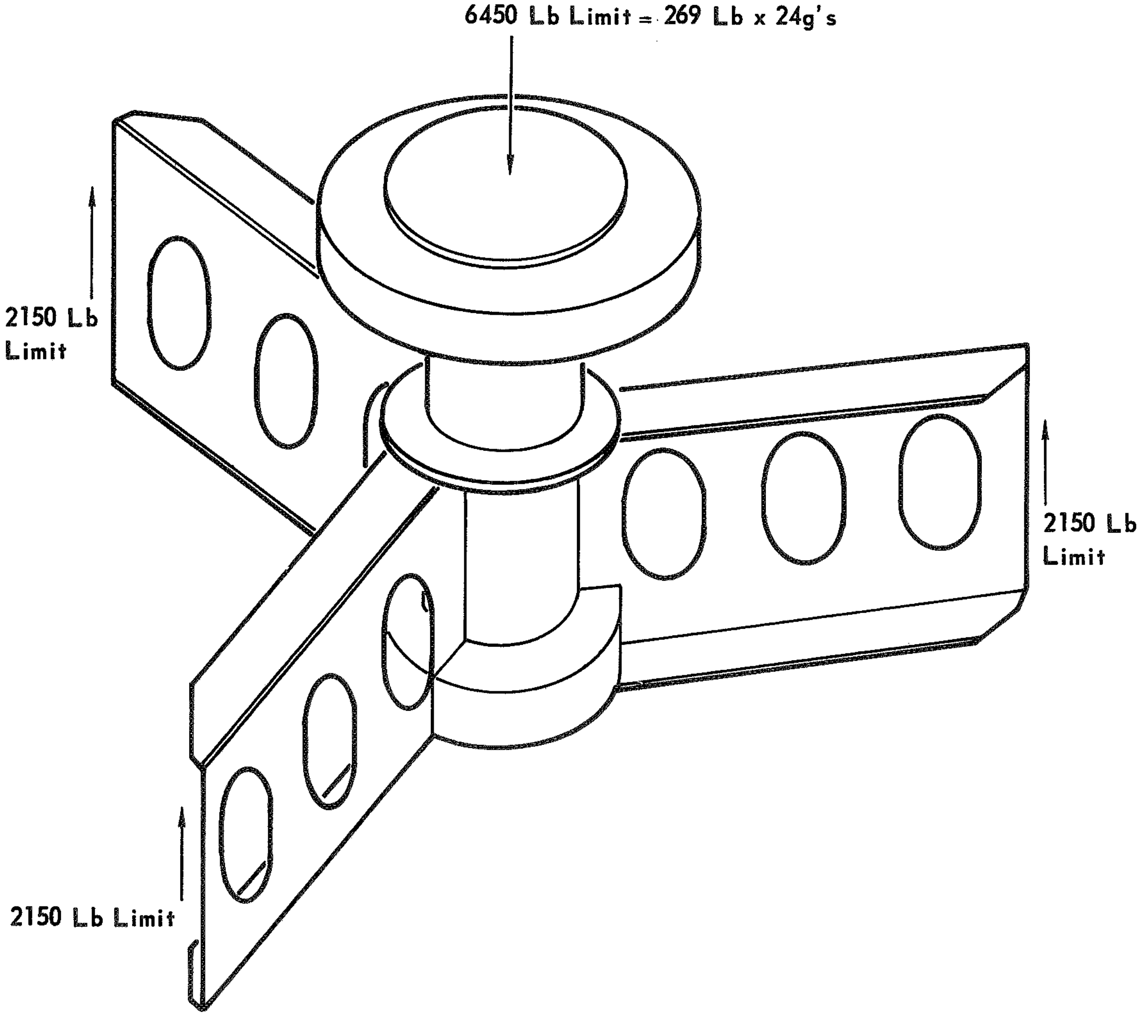


FIGURE 4–10

5. STRENGTH ANALYSIS

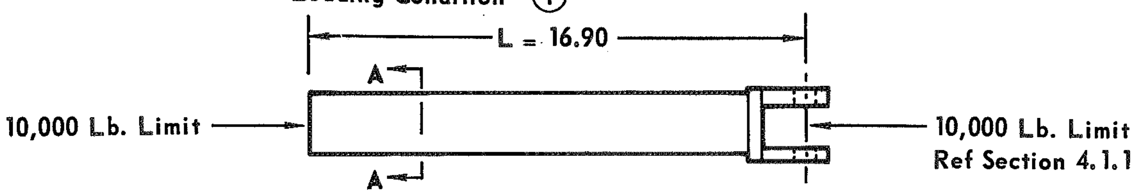
Strength analyses to substantiate the Margins of Safety of Section 1 are shown in this section. Loads are taken from Section 4 or derived as they are used. Methods of analysis used are those discussed in Section 3.4 or explained at the time they are used.

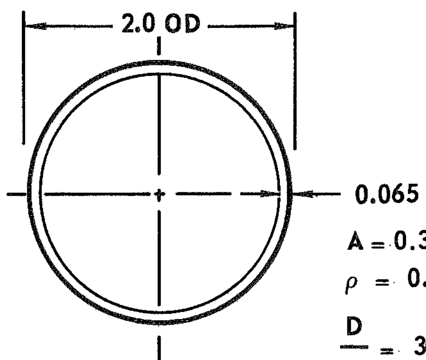
5.1 LANDING GEAR - The strength analysis of each portion of the landing gear is shown in the sections indicated below:

5.1.1 MAIN STRUT

STRENGTH ANALYSIS – PISTON ROD

Loading Condition ①





Section A – A

$A = 0.395\ \text{In.}^2$

$\rho = 0.685\ \text{In.}$

$\frac{D}{t} = 30.75$

Material:

2024–T3 Al. Tube

$F_{TU} = 66{,}000$ psi

$E_C = 10.7 \times 10^6$ psi

COLUMN STRENGTH OF PISTON ROD:

$P = 1.5 \times 10{,}000 = 15{,}000$ Lb. Ult.

$L' = L = 16.90$ (Assume Pin Ended)

$$\frac{L'}{\rho} = \frac{16.90}{0.685} = 24.7$$

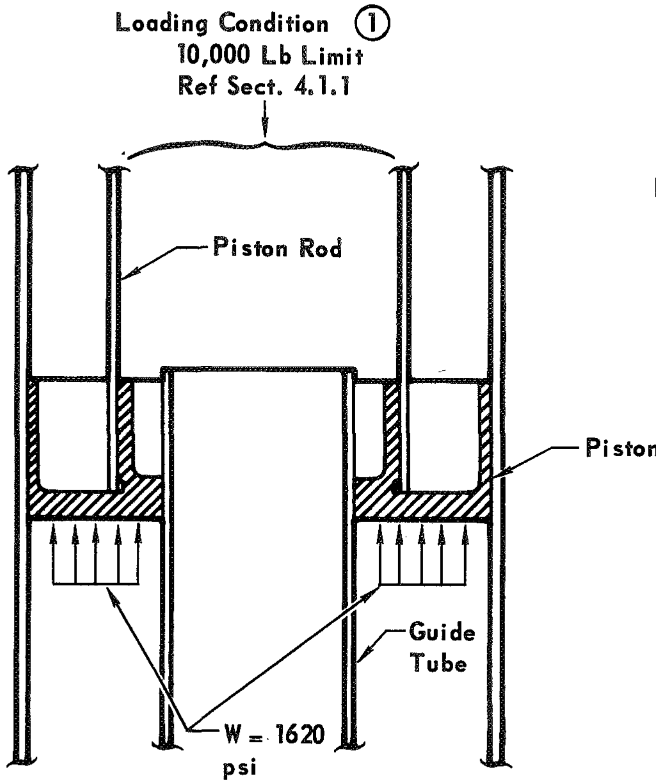
$F_{CC} = 46{,}000$ psi, Ref (3) Page 3.4.2.3

$$F_C = F_{CC} - \frac{F_{CC}^2}{4\pi^2 E}\left[\frac{L'}{\rho}\right]^2 = 46{,}000 - \frac{(46{,}000)^2}{4\pi^2 \times 10.7 \times 10^6}(24.7)^2 = 42{,}950 \text{ psi}$$

$$f_C = \frac{P}{A} = \frac{15{,}000}{0.395} = 37{,}900 \text{ psi}$$

$$M.S. = \frac{F_C}{f_C} - 1 = \frac{42{,}950}{37{,}900} - 1 = +\underline{\underline{0.13}}$$

STRENGTH ANALYSIS – PISTON

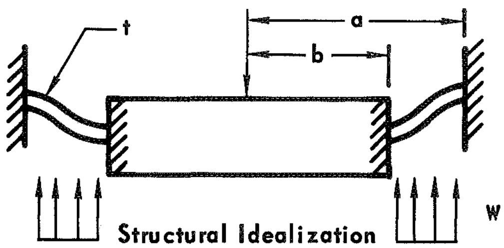


Piston Material:

A1. Bronze

F_{TU} = 100,000 psi

F_{TY} = 50,000 psi



Structural Idealization

a = 1.505 In.

b = 1.000 In.

t = 0.150 In.

BENDING CHECK OF PISTON:

Piston is Limit Load Critical

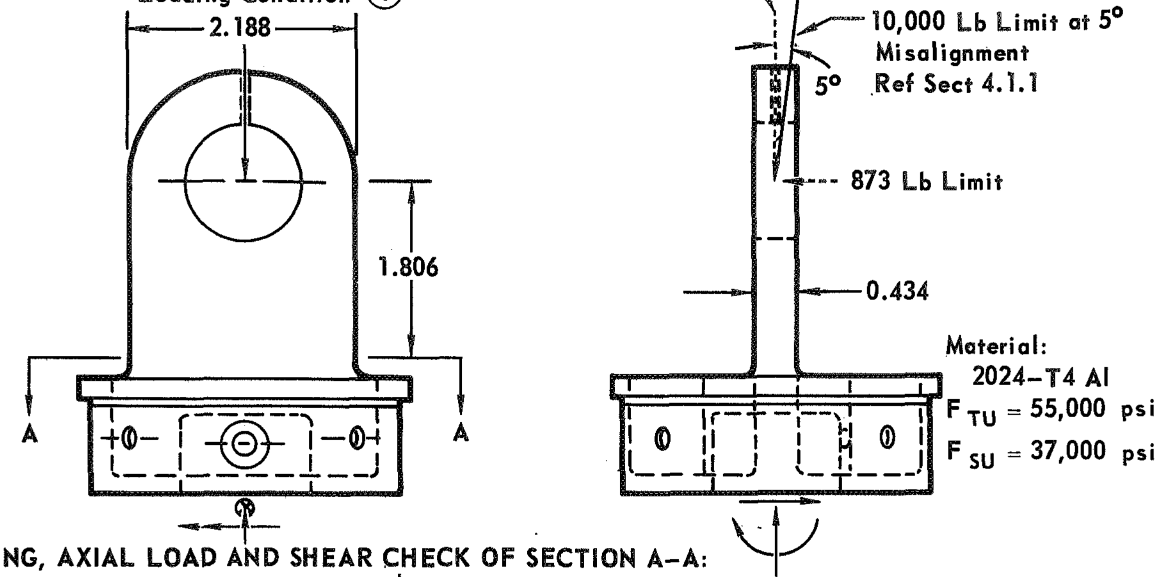
$$f_{MAX} = \frac{3w}{4t^2}\left[\frac{4a^4}{a^2-b^2}\log\frac{a}{b} - 3a^2 + b^2\right], \text{ Ref (5) Page 209 Case 58.}$$

$$f_{MAX} = \frac{3\times 1620}{4(0.15)^2}\left[\frac{4(1.505)^4}{(1.505)^2-(1.000)^2}\log\frac{1.505}{1.000} - 3\,(1.505)^2 + (1.000)^2\right] = 45{,}200 \text{ psi}$$

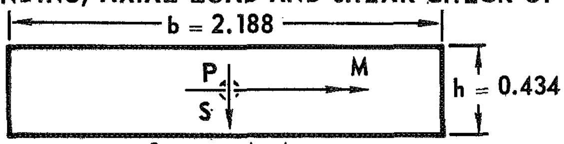
$$\text{M.S.} = \frac{F_{TY}}{f_{MAX}} - 1 = \frac{50{,}000}{45{,}200} - 1 = +\underline{\underline{0.10}}$$

STRENGTH ANALYSIS – LUG

Loading Condition (1)



BENDING, AXIAL LOAD AND SHEAR CHECK OF SECTION A–A:



Section A–A

$M = 1.5 \times 873 \times 1.806 = 2360$ In.-Lb Ult

$P = 1.5 \times 9970 = 14{,}960$ Lb Ult

$S = 1.5 \times 873 = 1310$ Lb Ult

$$M_{ALL} = 2Q_M F_{RB} = 2\left[\frac{bh^2}{8}\right] F_{RB}, \qquad F_{RB} = 0.93\, F_{TU}$$

$$= 2\left[\frac{2.188\,(0.434)^2}{8}\right] 0.93 \times 55{,}000 = 5260 \text{ In.-Lb}$$

$$P_{ALL} = F_{TU} A = F_{TU}\, bh = 55{,}000 \times 2.188 \times 0.434 = 52{,}200 \text{ Lb}$$

$$S_{ALL} = F_{SU} A = F_{SU}\, bh = 37{,}000 \times 2.188 \times 0.434 = 35{,}100 \text{ Lb}$$

$$R_B = \frac{M}{M_{ALL}} = \frac{2360}{5260} = 0.45, \qquad R_A = \frac{P}{P_{ALL}} = \frac{14{,}960}{52{,}200} = 0.29$$

$$(M.S.)_{B+A} = \frac{R_{Xa}}{R_B} - 1 = \frac{0.76}{0.45} - 1 = 0.69, \text{ Bending Plus Axial Load Only}$$

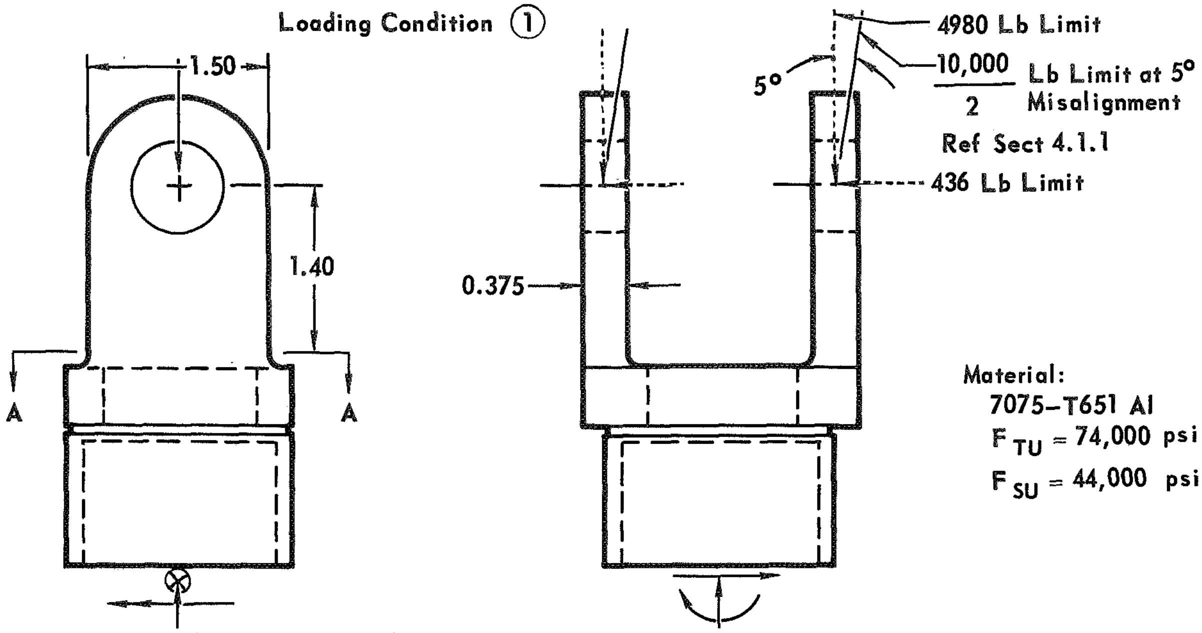
$$(M.S.)_S = \frac{S_{ALL}}{S} - 1 = \frac{35{,}100}{1310} - 1 = 25.80, \text{ Shear Only}$$

$$U_N = \frac{1}{(M.S.)_{B+A} + 1} = \frac{1}{0.69 + 1} = 0.59$$

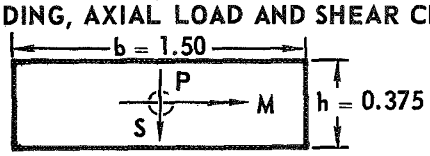
$$U_S = \frac{1}{(M.S.)_S + 1} = \frac{1}{25.80 + 1} = 0.04$$

$$M.S. = \frac{1}{\sqrt{U_S^{\,2} + U_N^{\,2}}} - 1 = \frac{1}{\sqrt{(0.04)^2 + (0.59)^2}} - 1 = +\underline{\underline{0.69}}$$

STRENGTH ANALYSIS – CLEVIS FITTING



BENDING, AXIAL LOAD AND SHEAR CHECK OF SECTION A–A:



Section A–A

$M = 1.5 \times 436 \times 1.40 = 916$ In.-Lb Ult

$P = 1.5 \times 4980 = 7480$ Lb Ult

$S = 1.5 \times 436 = 655$ Lb Ult

$$M_{ALL} = 2Q_M F_{RB} = 2\left[\frac{bh^2}{8}\right] F_{RB} \qquad F_{RB} = 0.96\, F_{TU},$$

$$= 2\left[\frac{1.5\,(0.375)^2}{8}\right] 0.96 \times 74{,}000 = 3750 \text{ In.-Lb}$$

$$P_{ALL} = F_{TU} A = F_{TU} bh = 74{,}000 \times 1.50 \times 0.375 = 41{,}700 \text{ Lb}$$

$$S_{ALL} = F_{SU}\, A = F_{SU}\, bh = 44{,}000 \times 1.50 \times 0.375 = 24{,}800 \text{ Lb}$$

$$R_B = \frac{M}{M_{ALL}} = \frac{916}{3750} = 0.24, \qquad R_A = \frac{P}{P_{ALL}} = \frac{7480}{41{,}700} = 0.18$$

$$(M.S.)_{B+A} = \frac{R_{Xa}}{R_B} - 1 = \frac{0.71}{0.24} - 1 = 1.96, \text{ Bending Plus Axial Load Only}$$

$$(M.S.)_S = \frac{S_{ALL}}{S} - 1 = \frac{24{,}800}{655} - 1 = 36.86, \text{ Shear Only}$$

$$U_N = \frac{1}{(M.S.)_{B+A}+1} = \frac{1}{1.96+1} = 0.34$$

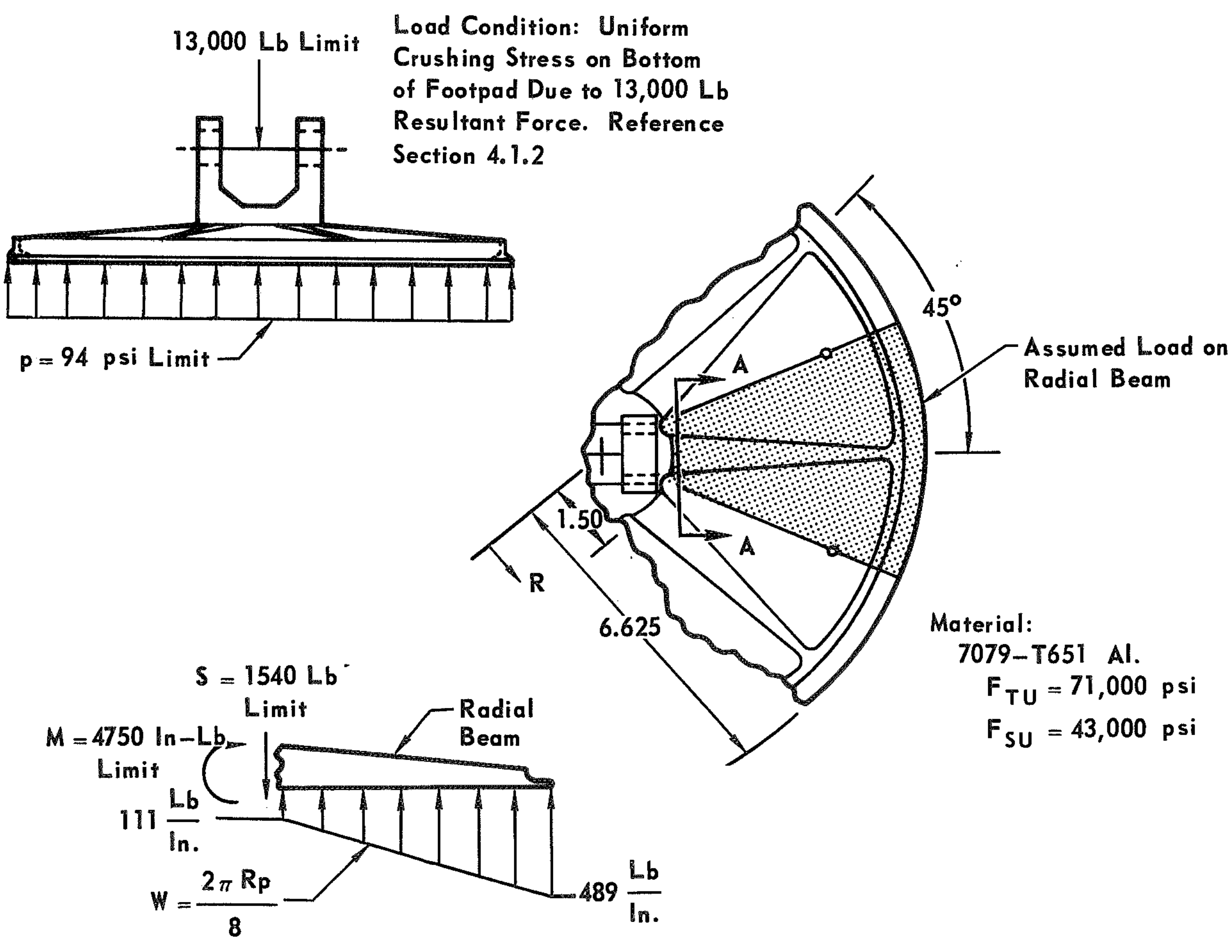
$$U_S = \frac{1}{(M.S.)_S+1} = \frac{1}{36.86+1} = 0.03$$

$$M.S. = \frac{1}{\sqrt{U_S^2+U_N^2}} - 1 = \frac{1}{\sqrt{(0.03)^2+(0.34)^2}} - 1 = +\underline{\underline{1.93}}$$

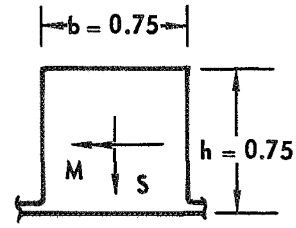
5.1.2 FOOTPAD

STRENGTH ANALYSIS – RADIAL BEAM

Loading Condition (2)



BENDING AND SHEAR CHECK OF SECTION A–A:



SECTION A–A

$M = 1.5 \times 4750 = 7100$ In.-Lb Ult

$S = 1.5 \times 1540 = 2310$ Lb Ult

$$M_{ALL} = 2Q_M F_{RB} = 2\left[\frac{bh^2}{8}\right] F_{RB}, \qquad F_{RB} = 0.96\, F_{TU}$$

$$M_{ALL} = 2\left[\frac{0.75 \times 0.75^2}{8}\right] 0.96 \times 71{,}000 = 7150 \text{ In.-Lb}$$

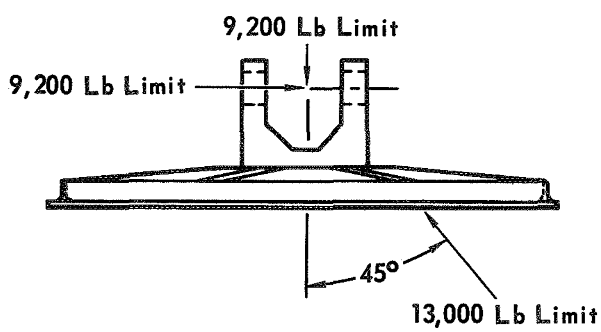
$$S_{ALL} = F_{SU} A = F_{SU} bh = 43{,}000 \times 0.75 \times 0.75 = 24{,}200 \text{ Lb}$$

$$R_B = \frac{M}{M_{ALL}} = \frac{7100}{7150} = 0.99 \qquad R_S = \frac{S}{S_{ALL}} = \frac{2310}{24{,}200} = 0.10$$

$$M.S. = \frac{1}{\sqrt{{R_B}^2 + {R_S}^2}} - 1 = \frac{1}{\sqrt{(0.99)^2 + (0.10)^2}} - 1 = \underline{\underline{0.00}}$$

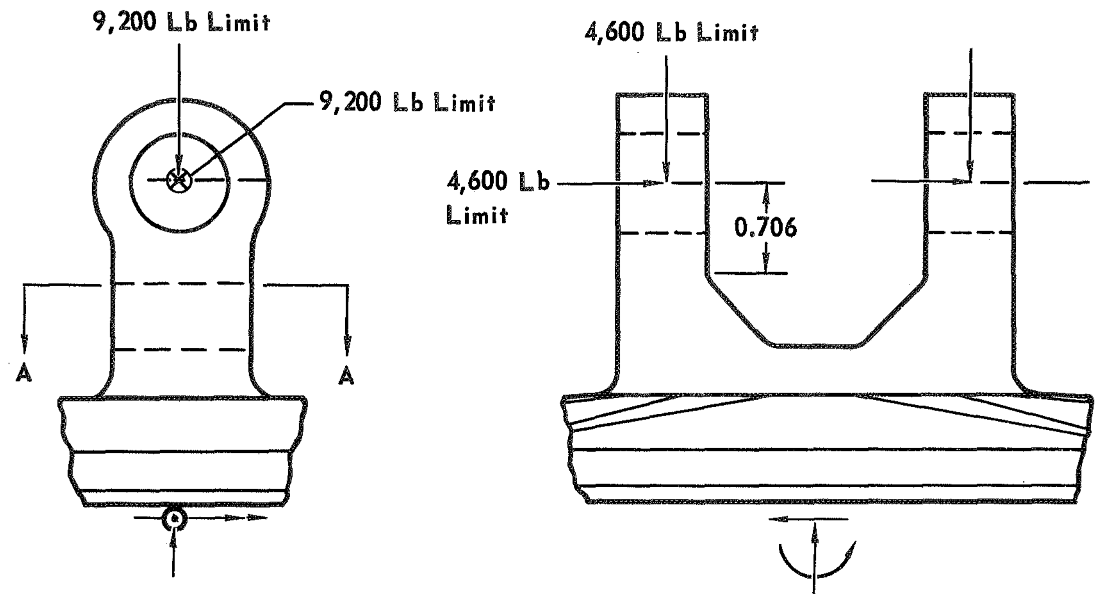
STRENGTH ANALYSIS – LUG

Loading Condition (2)

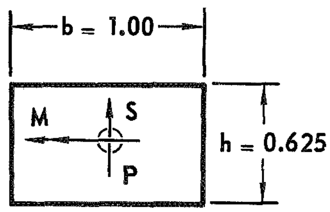


Load Condition: 13,000 Lb Resultant Force Acting At 45° Due To Coefficient Of Friction Of Unity. Reference Section 4.1.2

Material:
7079–T651 Al.
$F_{TU} = 71{,}000$ psi
$F_{SU} = 43{,}000$ psi



BENDING, AXIAL LOAD AND SHEAR CHECK OF SECTION A–A :



Section A–A

$M = 1.5 \times 4{,}600 \times 0.706 = 4{,}870$ In.–Lb Ult.
$P = 1.5 \times 4{,}600 = 6{,}900$ Lb Ult.
$S = 1.5 \times 4600 = 6{,}900$ Lb Ult.

$$M_{ALL} = 2Q_M F_{RB} = 2\left[\frac{bh^2}{8}\right] F_{RB} \qquad F_{RB} = 0.96\ F_{TU}$$

$$M_{ALL} = 2\left[\frac{1.00\ (0.625)^2}{8}\right] 0.96 \times 71{,}000 = 6{,}650 \text{ In.–Lb.}$$

$$P_{ALL} = F_{TU}\ A = F_{TU}\ bh = 71{,}000 \times 1.00 \times 0.625 = 44{,}400 \text{ Lb.}$$

$$S_{ALL} = F_{SU}\ A = F_{SU}\ bh = 43{,}000 \times 1.00 \times 0.625 = 26{,}900 \text{ Lb.}$$

$$R_B = \frac{M}{M_{ALL}} = \frac{4{,}870}{6{,}650} = 0.73, \qquad R_A = \frac{P}{P_{ALL}} = \frac{6{,}900}{44{,}400} = 0.16$$

$$(M.S.)_{B+A} = \frac{R_{Xa}}{R_B} - 1 = \frac{0.96}{0.73} - 1 = 0.31, \text{ Bending Plus Axial Load}$$

$$(M.S.)_S = \frac{S_{ALL}}{S} - 1 = \frac{26{,}900}{6{,}900} - 1 = 2.90, \text{ Shear Only}$$

$$U_N = \frac{1}{(M.S.)_{B+A} + 1} = \frac{1}{0.31 + 1} = 0.76$$

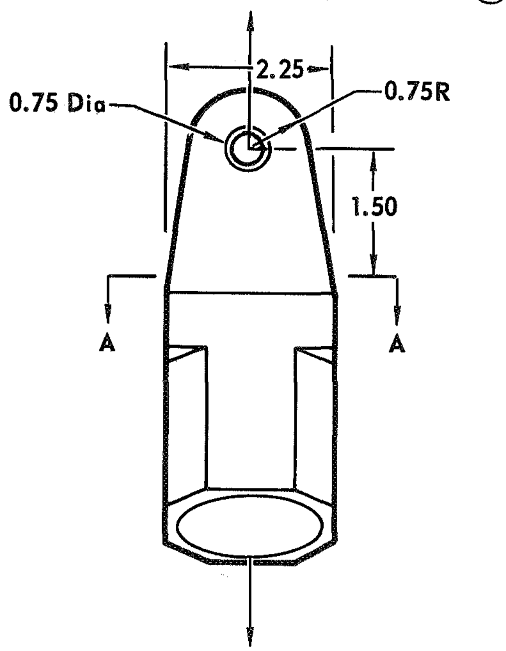
$$U_S = \frac{1}{(M.S.)_S + 1} = \frac{1}{2.90 + 1} = 0.26$$

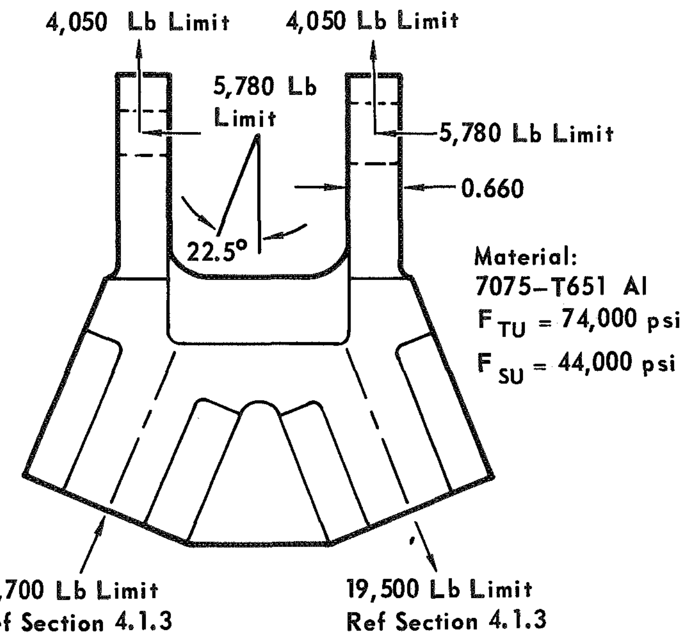
$$M.S. = \frac{1}{\sqrt{U_S^2 + U_N^2}} - 1 = \frac{1}{\sqrt{(0.26)^2 + (0.76)^2}} - 1 = \underline{\underline{+0.24}}$$

5.1.3 A–FRAME

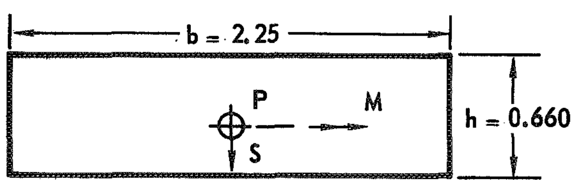
STRENGTH ANALYSIS – APEX FITTING

Loading Condition (3)





BENDING, AXIAL LOAD AND SHEAR CHECK OF SECTION A–A:



Section A–A

$M = 1.5 \times 5{,}780 \times 1.50 = 13{,}000$ In.–Lb Ult.
$P = 1.5 \times 4{,}050 = 6{,}070$ Lb Ult.
$S = 1.5 \times 5{,}780 = 8{,}670$ Lb Ult.

$$M_{ALL} = 2Q_M F_{RB} = 2\left[\frac{bh^2}{8}\right]F_{RB}, \qquad F_{RB} = 0.96\ F_{TU}$$

$$= 2\left[\frac{2.25\ (0.660)^2}{8}\right]0.96 \times 74{,}000 = 17{,}400\ \text{In.-Lb}$$

$$P_{ALL} = F_{TU}\ A = F_{TU}\ bh = 74{,}000 \times 2.25 \times 0.660 = 110{,}000\ \text{Lb}$$

$$S_{ALL} = F_{SU}\ A = F_{SU}\ bh = 44{,}000 \times 2.25 \times 0.660 = 65{,}400\ \text{Lb}$$

$$R_B = \frac{M}{M_{ALL}} = \frac{13{,}000}{17{,}400} = 0.75, \quad R_A = \frac{P}{P_{ALL}} = \frac{6{,}070}{110{,}000} = 0.06$$

$$(M.S.)_{B+A} = \frac{R_{Xa}}{R_B} - 1 = \frac{0.99}{0.75} - 1 = 0.32, \text{ Bending Plus Axial Load Only}$$

$$(M.S.)_S = \frac{S_{ALL}}{S} - 1 = \frac{65{,}400}{8{,}670} - 1 = 6.55, \text{ Shear Only}$$

$$U_N = \frac{1}{(M.S.)_{B+A} + 1} = \frac{1}{0.32 + 1} = 0.76$$

$$U_S = \frac{1}{(M.S.)_S + 1} = \frac{1}{6.55 + 1} = 0.13$$

$$M.S. = \frac{1}{\sqrt{U_S^2 + U_N^2}} - 1 = \frac{1}{\sqrt{(0.13)^2 + (0.76)^2}} - 1 = \underline{\underline{+0.29}}$$

LUG CHECK:

$$\frac{R}{D} = \frac{0.75}{0.75} = 1.00 \qquad P = 1.5 \times 4{,}050 = 6{,}070\ \text{Lb Ult.}$$

$$\frac{D}{t} = \frac{0.75}{0.660} = 1.14$$

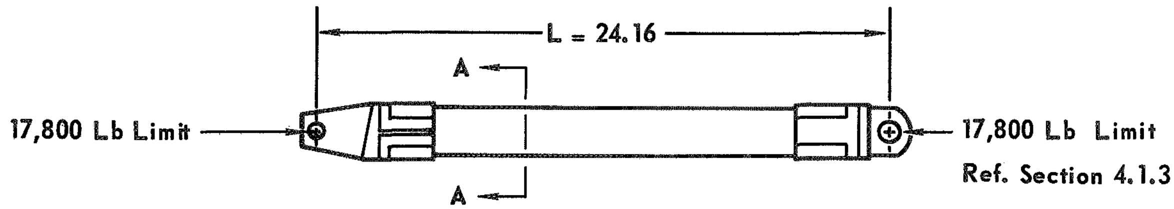
$K_{BRU} = 0.99$, Ref (6) Page D1.7

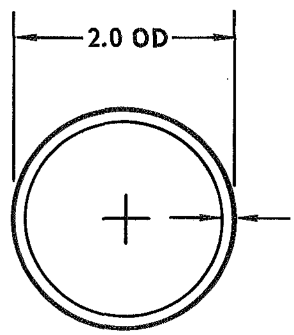
$$P_{BRU} = K_{BRU}\ F_{TU}\ Dt = 0.99 \times 74{,}000 \times 0.75 \times 0.660 = 36{,}300\ \text{Lb.}$$

$$M.S. = \frac{P_{BRU}}{P} - 1 = \frac{36{,}300}{6{,}070} - 1 = \underline{\underline{+4.99}}$$

STRENGTH ANALYSIS – A-FRAME TUBE

Loading Condition (4)





$A = 0.709 \text{ In.}^2$

$\rho = 0.666 \text{ In.}$

$\frac{D}{t} = 16.67$

Section A – A

Material:
2024–T3 Al. Tube
$F_{TU} = 66{,}000$ psi
$E_C = 10.7 \times 10^6$ psi

COLUMN STRENGTH OF TUBE:

$$P = 1.5 \times 17{,}800 = 26{,}700 \text{ Lb. Ult.}$$

$L' = L = 24.16$ (Assume Pin Ended)

$$\frac{L'}{\rho} = \frac{24.16}{0.666} = 36.3$$

$F_{CC} = 47{,}000$ psi, Ref. (3) Page 3.4.2.3

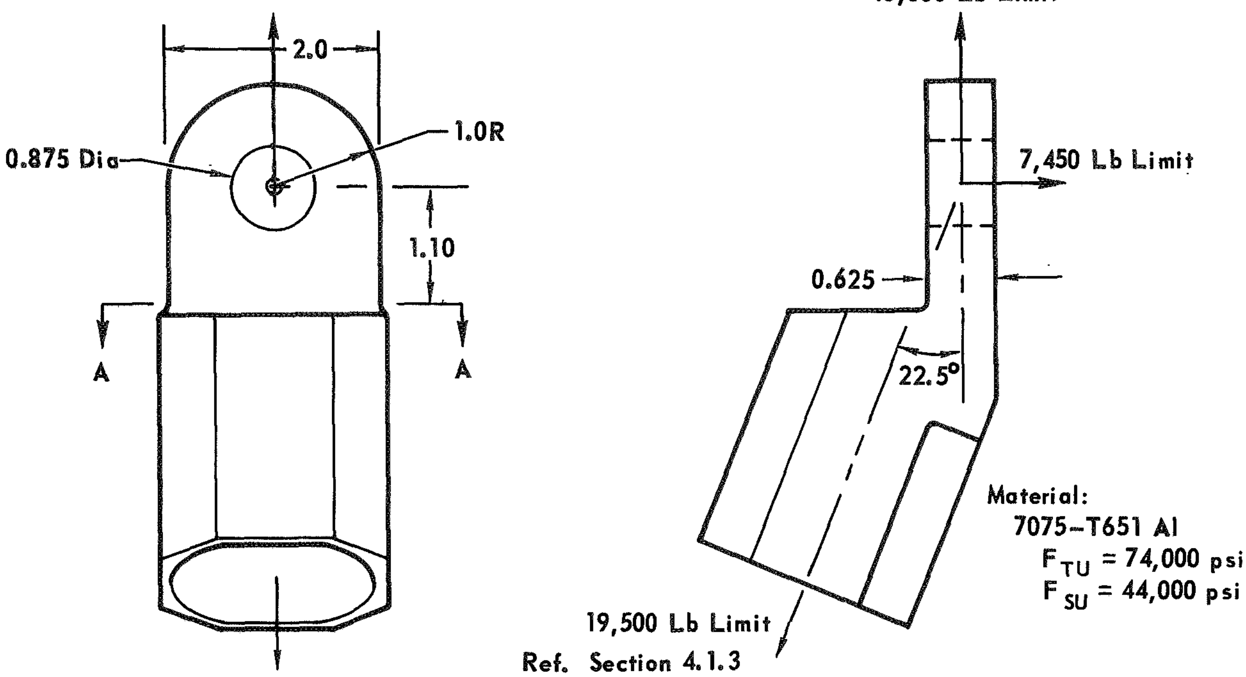
$$F_C = F_{CC} - \frac{F_{CC}^2}{4\pi^2 E}\left[\frac{L'}{\rho}\right]^2 = 47{,}000 - \frac{(47{,}000)^2}{4\pi^2 \times 10.7 \times 10^6}(36.3)^2 = 40{,}100 \text{ psi}$$

$$f_C = \frac{P}{A} = \frac{26{,}700}{0.709} = 37{,}700 \text{ psi}$$

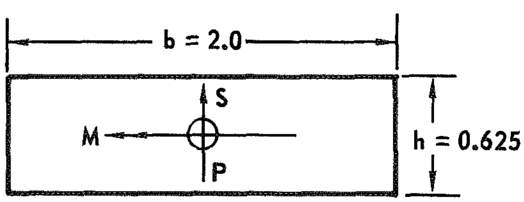
$$M.S. = \frac{F_C}{f_C} - 1 = \frac{40{,}100}{37{,}700} - 1 = +\underline{\underline{0.06}}$$

STRENGTH ANALYSIS – LUG

Loading Condition (3)



BENDING, AXIAL LOAD AND SHEAR CHECK OF SECTION A–A:



Section A–A

M = 1.5 x 7,450 x 1.10 = 12,300 In.-Lb Ult
P = 1.5 x 18,000 = 27,000 Lb Ult
S = 1.5 x 7,450 = 11,200 Lb Ult

$$M_{ALL} = 2Q_M F_{RB} = 2\left[\frac{bh^2}{8}\right] F_{RB}, \qquad F_{RB} = 0.96\ F_{TU},$$

$$= 2\left[\frac{2(0.625)^2}{8}\right] 0.96 \times 74{,}000 = 13{,}900 \text{ In.-Lb}$$

$$P_{ALL} = F_{TU}A = F_{TU}bh = 74{,}000 \times 2.0 \times 0.625 = 92{,}500 \text{ Lb}$$

$$S_{ALL} = F_{SU}A = F_{SU}bh = 44{,}000 \times 2.0 \times 0.625 = 55{,}000 \text{ Lb}$$

$$R_B = \frac{M}{M_{ALL}} = \frac{12{,}300}{13{,}900} = 0.88, \qquad R_A = \frac{P}{P_{ALL}} = \frac{27{,}000}{92{,}500} = 0.29$$

$$(M.S.)_{B+A} = \frac{R_{Xa}}{R_B} - 1 = \frac{0.91}{0.88} - 1 = 0.03, \text{ Bending Plus Axial Load Only}$$

$$(M.S.)_S = \frac{S_{ALL}}{S} - 1 = \frac{55{,}000}{11{,}200} - 1 = 3.90, \text{ Shear Only}$$

$$U_N = \frac{1}{(M.S.)_{B+A} + 1} = \frac{1}{0.03 + 1} = 0.97$$

$$U_S = \frac{1}{(M.S.)_S + 1} = \frac{1}{3.90 + 1} = 0.20$$

$$M.S. = \frac{1}{\sqrt{U_S^2 + U_N^2}} - 1 = \frac{1}{\sqrt{(0.20)^2 + (0.97)^2}} - 1 = \underline{\underline{+0.01}}$$

LUG CHECK:

$$\frac{R}{D} = \frac{1}{0.875} = 1.14 \qquad P = 1.5 \times 18{,}000 = 27{,}000 \text{ Lb Ult}$$

$$\frac{D}{t} = \frac{0.875}{0.625} = 1.40$$

$K_{BRU} = 1.14$, Ref. (6) Page D 1.7

$P_{BRU} = K_{BRU}\, F_{TU}\, Dt = 1.14 \times 74{,}000 \times 0.875 \times 0.625 = 46{,}000$ Lb.

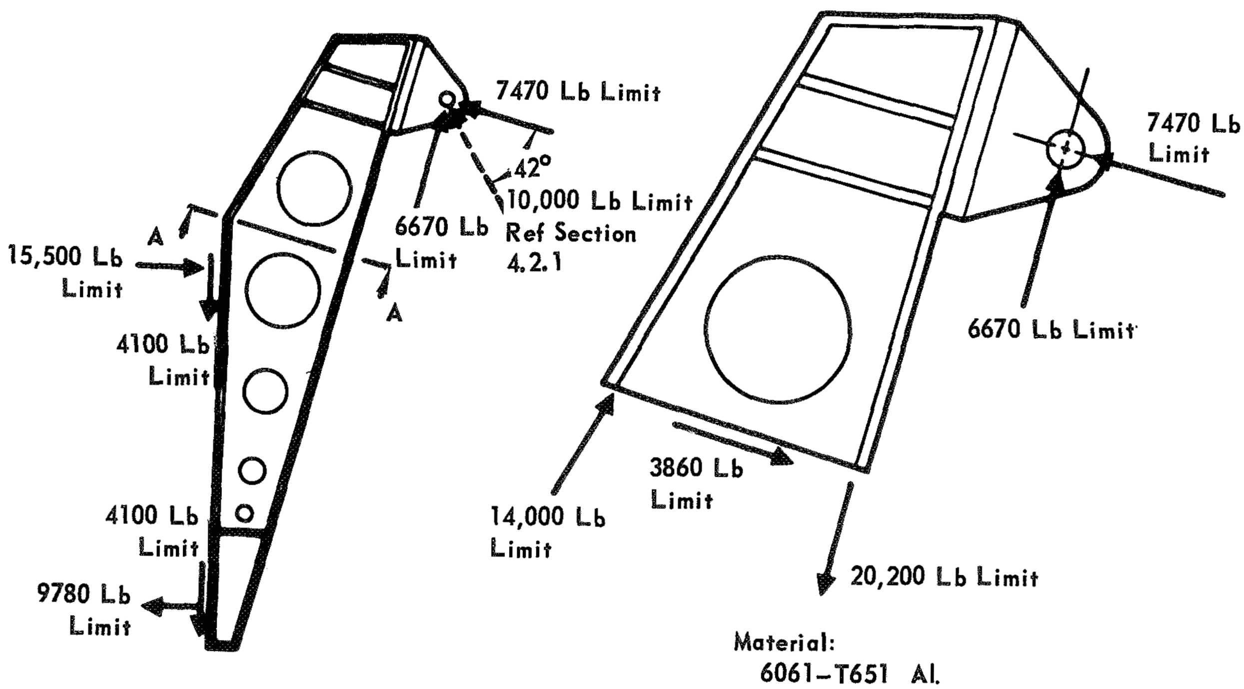
$$M.S. = \frac{P_{BRU}}{P} - 1 = \frac{46{,}000}{27{,}000} - 1 = \underline{\underline{+0.70}}$$

5.2 CENTER BODY - The strength analysis of each portion of the center body is shown in sections indicated below:

5.2.1 MAIN STRUT SUPPORT BEAM

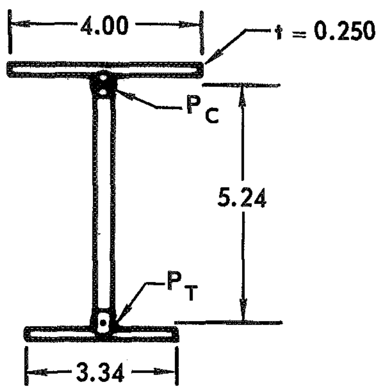
STRENGTH ANALYSIS - BEAM

Loading Condition (1)



Material:
6061-T651 Al.
F_{TU} = 42,000 PSI

BENDING CHECK OF SECTION A–A:



Section A–A
(Rotated 75° Clockwise)

$P_T = 1.5 \times 20{,}200 = 30{,}300$ Lb Ult

$P_C = 1.5 \times 14{,}000 = 21{,}000$ Lb Ult

$A_T = 1.023 \text{ In.}^2$, Tension Cap Area

$A_C = 1.188 \text{ In.}^2$, Compression Cap Area

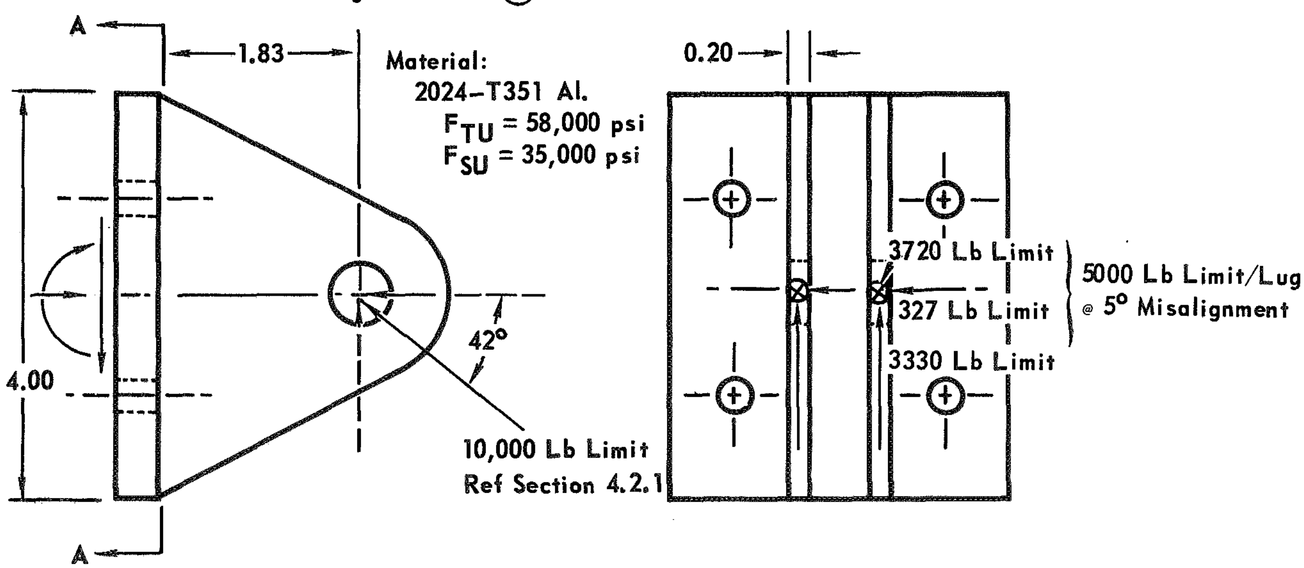
Section A–A is Tension Cap Critical

$P_{T_{ALL}} = F_{TU} A_T = 42{,}000 \times 1.023 = 43{,}000$ Lb

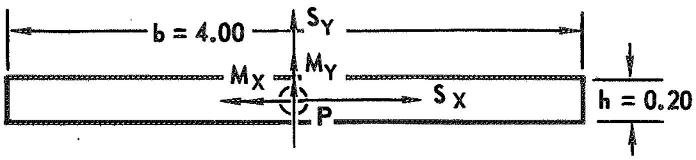
$$M.S. = \frac{P_{T_{ALL}}}{P_T} - 1 = \frac{43{,}000}{30{,}300} - 1 = \underline{\underline{+0.42}}$$

STRENGTH ANALYSIS – CLEVIS FITTING

Loading Condition ①



COMPLEX BENDING, AXIAL LOAD AND SHEAR CHECK OF SECTION A–A:



Section A–A (Rotated Clockwise 90°)

$M_X = 1.5 \times 327 \times 1.83 = 896$ In.-Lb Ult
$M_Y = 1.5 \times 3{,}330 \times 1.83 = 9{,}140$ In.-Lb Ult
$P = 1.5 \times 3{,}720 = 5{,}590$ Lb Ult
$S_X = 1.5 \times 3330 = 4995$ Lb Ult
$S_Y = 1.5 \times 327 = 490$ Lb Ult

$$M_{X_{ALL}} = 2Q_M F_{RB} = 2\left[\frac{bh^2}{8}\right] F_{RB}, \quad F_{RB} = 0.93\ F_{TU}$$

$$= 2\left[\frac{4.0\ (0.20)^2}{8}\right] 0.93 \times 58{,}000 = 2{,}160 \text{ In.-Lb}$$

$$M_{Y_{ALL}} = 2Q_M F_{RB} = 2\left[\frac{hb^2}{8}\right] F_{RB}$$

$$= 2\left[\frac{0.20\ (4.00)^2}{8}\right] 0.93 \times 58{,}000 = 43{,}300 \text{ In-Lb}$$

$$P_{ALL} = F_{TU} A = F_{TU}\, bh = 58{,}000 \times 4.00 \times 0.20 = 46{,}500 \text{ Lb}$$

$$S_{X_{ALL}} = S_{Y_{ALL}} = F_{SU} A = F_{SU}\, bh = 35{,}000 \times 4.00 \times 0.20 = 28{,}000 \text{ Lb}$$

$$R_{BX} = \frac{M_X}{M_{X_{ALL}}} = \frac{896}{2{,}160} = 0.42 \qquad R_{BY} = \frac{M_Y}{M_{Y_{ALL}}} = \frac{9{,}140}{43{,}300} = 0.21$$

$$R_A = \frac{P}{P_{ALL}} = \frac{5{,}590}{46{,}500} = 0.12$$

$$\frac{R_A}{R_{BX}} = \frac{0.12}{0.42} = 0.29, \qquad \frac{R_A}{R_{BY}} = \frac{0.12}{0.21} = 0.57,$$ The Smaller Value is Used to Determine M.S.

$$(M.S.)_{B+A} = \frac{R_{X_a}}{R_{BX}} - 1 = \frac{0.81}{0.42} - 1 = 0.92,$$ Bending Plus Axial Load Only

$$R_{SX} = \frac{S_X}{S_{X_{ALL}}} = \frac{4{,}995}{28{,}000} = 0.18 \qquad R_{SY} = \frac{S_Y}{S_{Y_{ALL}}} = \frac{490}{28{,}000} = 0.02$$

$$(M.S.)_S = \frac{1}{\sqrt{R_{S_X}{}^2 + R_{S_Y}{}^2}} - 1 = \frac{1}{\sqrt{(0.18)^2 + (0.02)^2}} - 1 = 4.52, \text{ Shear Only}$$

$$U_N = \frac{1}{(M.S.)_{B+A} + 1} = \frac{1}{0.92 + 1} = 0.52$$

$$U_S = \frac{1}{(M.S.)_S + 1} = \frac{1}{4.52 + 1} = 0.18$$

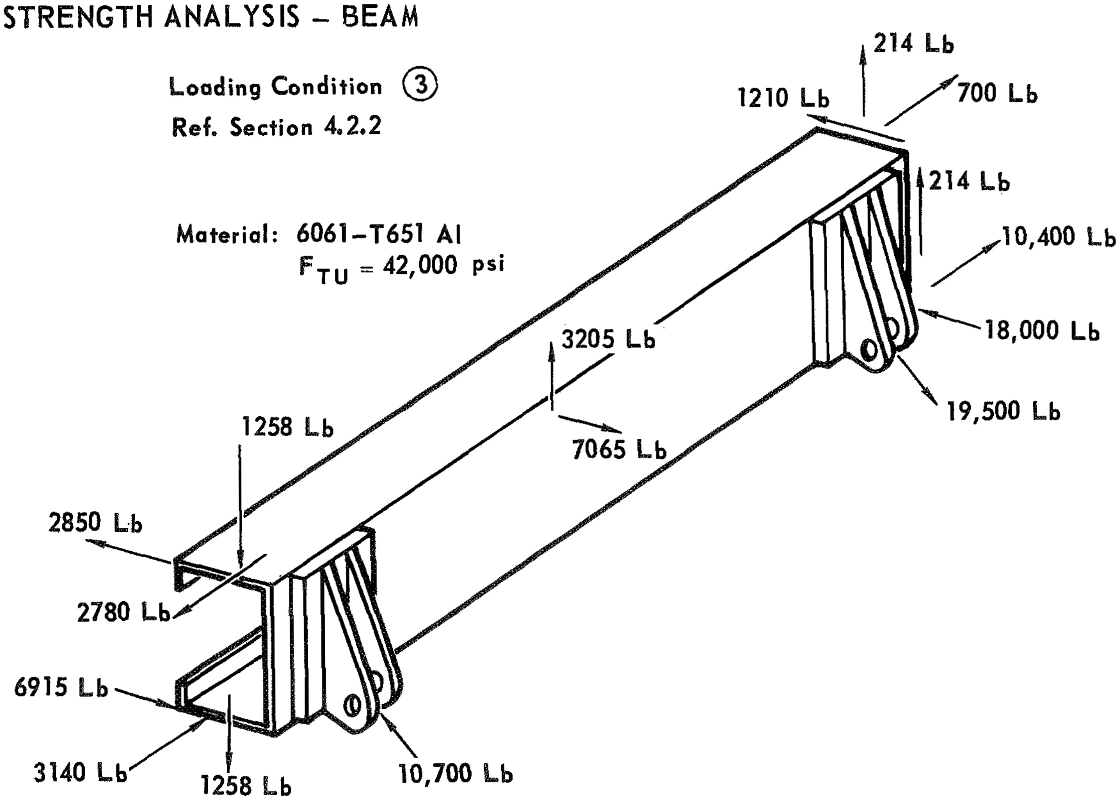
$$M.S. = \frac{1}{\sqrt{U_S{}^2 + U_N{}^2}} - 1 = \frac{1}{\sqrt{(0.18)^2 + (0.52)^2}} - 1 = +\underline{\underline{0.82}}$$

5.2.2 INTERFACE

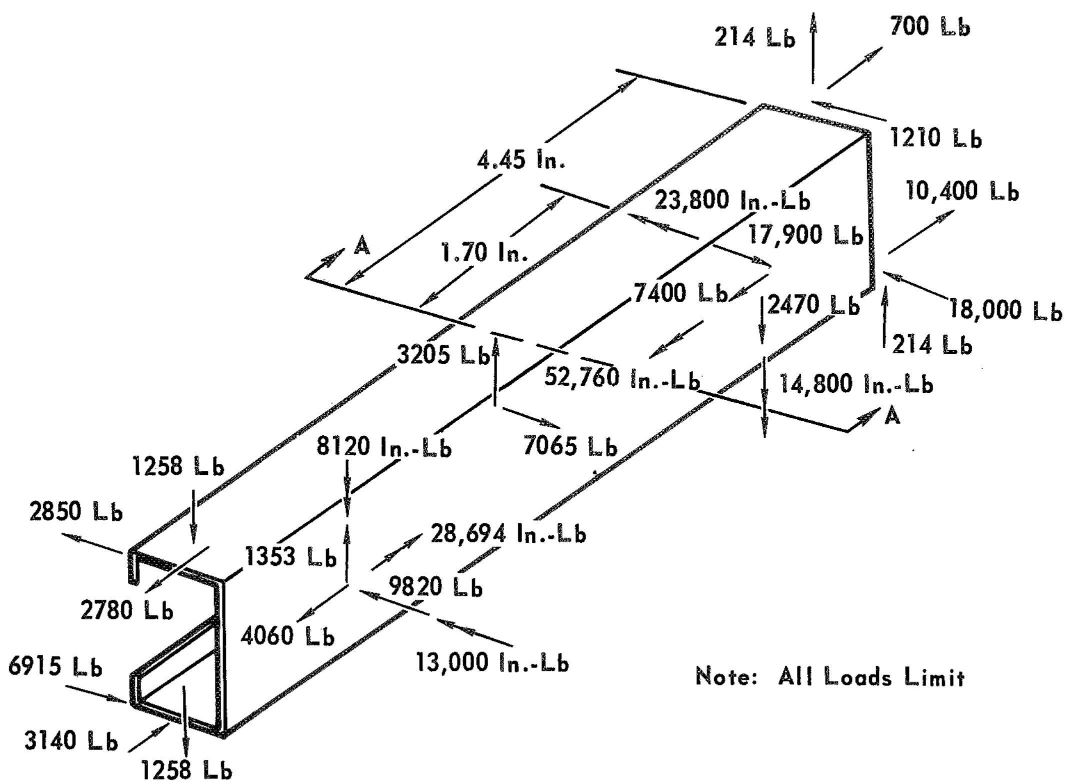
STRENGTH ANALYSIS – BEAM

Loading Condition (3)
Ref. Section 4.2.2

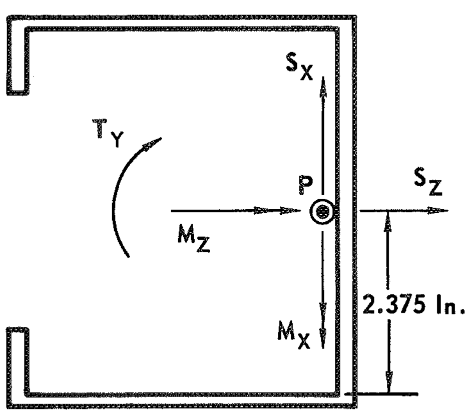
Material: 6061-T651 Al
F_{TU} = 42,000 psi



(a) Forces Applied to Beam



(b) Load Resultants on Beam



M_X = 1.5 x 40,250 = 60,375 In.-Lb Ult

T_Y = 1.5 x 12,750 = 19,140 In.-Lb Ult

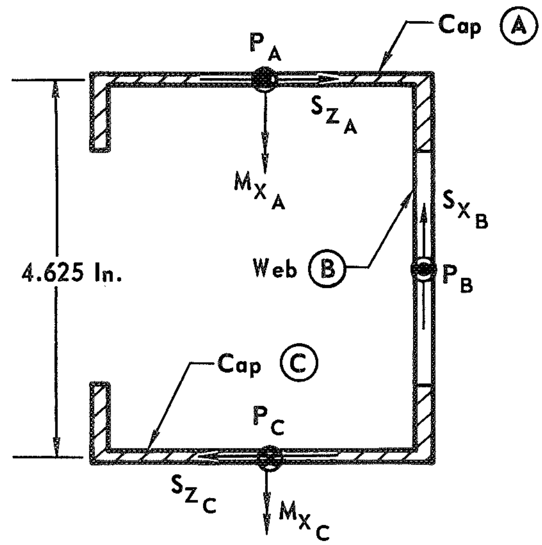
M_Z = 1.5 x 3223 = 4840 In.-Lb Ult

S_X = 1.5 x 2042 = 3065 Lb Ult

P = 1.5 x 3700 = 5550 Lb Ult

S_Z = 1.5 x 1310 = 1960 Lb Ult

(c) Internal Load Resultants on Section A–A



M_{X_A} = 2625 In.- Lb Ult

P_A = 1046 Lb Ult

S_{Z_A} = 5120 Lb Ult

S_{X_B} = 3065 Lb Ult

P_B = 5550 Lb Ult

M_{X_C} = 57,750 In.-Lb Ult

P_C = 1046 Lb Ult

S_{Z_C} = 3160 Lb Ult

(d) Distribution of Internal Loads on Section A–A

Assumptions:

1. Axial Load, P and Shear, S_X Carried by Web (B)

   $P_B = P = 5550$ Lb Ult

   $S_{X_B} = S_X = 3065$ Lb Ult

2. Bending Moment, M_Z Carried by Tension in Cap (A) and Compression in Cap (C)

   $P_A = -P_C = M_Z/4.625 = 1046$ Lb Ult

3. Bending Moment, M_X Carried by Bending of Caps (A) and (C). Twisting Moment T_Y Carried by Differential Bending in Caps (A) and (C)

   $M_X = M_{X_A} + M_{X_C} = 60{,}375$ In.-Lb Ult

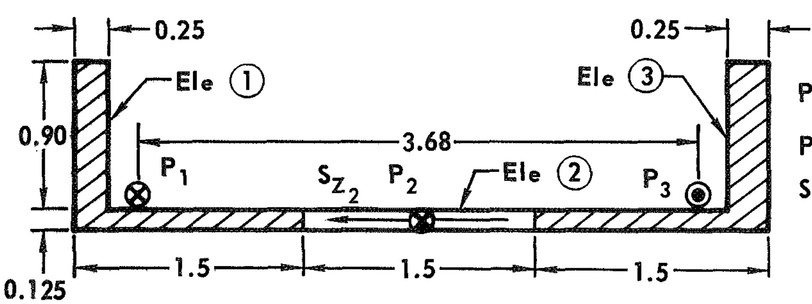
   $$M_{X_A} = \left[1210 \times 4.45 - 17{,}900 \times \frac{2.375}{4.625} \times 1.7 - \frac{14{,}800}{2.0} + \frac{52{,}760}{4.625} \times 1.7\right] 1.5 = 2625 \text{ In.-Lb Ult}$$

   $$M_{X_C} = \left[18{,}000 \times 4.45 - 17{,}900 \times \frac{2.250}{4.625} \times 1.7 - \frac{14{,}800}{2.0} - \frac{52{,}760}{4.625} \times 1.7\right] \times 1.5 = 57{,}750 \text{ In.-Lb Ult}$$

4. Shear Load, S_Z Carried Equally by Caps (A) and (C). Total Shear in Caps (A) and (C) Includes Shear Resulting from Twisting Moment T_Y

$$S_{Z_A} = \frac{T_Y}{4.625} + \frac{S_Z}{2} = \frac{19{,}140}{4.625} + \frac{1960}{2.0} = 5120 \text{ Lb Ult}, \quad S_{Z_C} = \frac{T_Y}{4.625} - \frac{S_Z}{2} = \frac{19{,}140}{4.625} - \frac{1960}{2.0} = 3160 \text{ Lb Ult}$$

Cap (C) is Critical Because of Large Bending Moment, M_{X_C}



$P_1 = P_3 = M_{X_C}/3.68 = 15{,}700$ Lb Ult

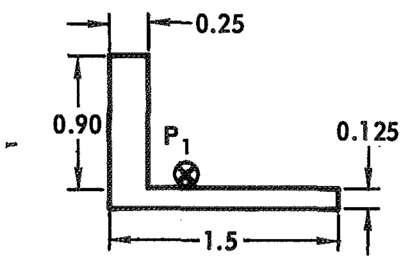
$P_2 = P_C = 1046$ Lb Ult

$S_{Z_2} = S_{Z_C} = 3160$ Lb Ult

(e) Distribution of Loads on Cap (C)

Element (1) of Cap (C) is Critical

AXIAL LOAD CHECK OF ELEMENT (1):



P_1 = 15,700 Lb Ult

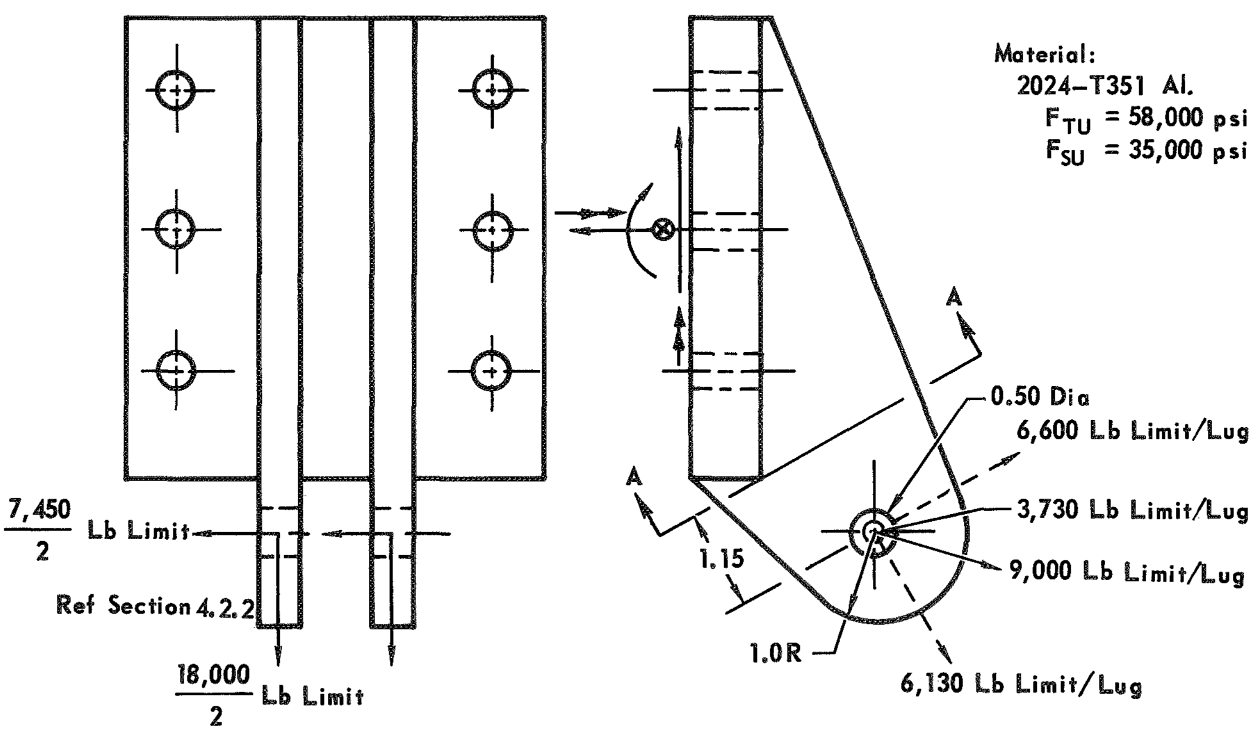
$P_{ALL} = A\,F_{CC}$ For this Section, $F_{CC} = F_{TU}$ = 42,000 psi

= [0.25 (0.90) + 1.5 (0.125)] x 42,000 = 17,300 Lb Ult

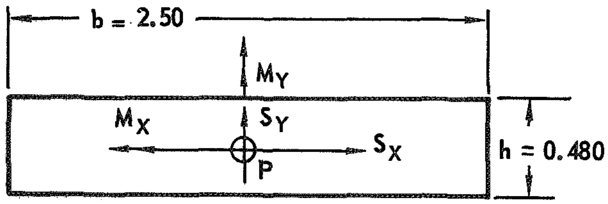
$$M.S. = \frac{P_{ALL}}{P_1} - 1 = \frac{17,300}{15,700} - 1 = +\underline{\underline{0.10}}$$

STRENGTH ANALYSIS – CLEVIS FITTING

Loading Condition (3)



COMPLEX BENDING, AXIAL LOAD AND SHEAR CHECK OF SECTION A–A:



Section A–A (Rotated Clockwise 30°)

$M_X = 1.5 \times 3{,}730 \times 1.15 = 6{,}450$ In.-Lb Ult
$M_Y = 1.5 \times 6{,}600 \times 1.15 = 11{,}400$ In.-Lb Ult
$P = 1.5 \times 6{,}130 = 9{,}200$ Lb Ult
$S_X = 1.5 \times 6{,}600 = 9{,}900$ Lb Ult
$S_Y = 1.5 \times 3{,}730 = 5{,}600$ Lb Ult

$$M_{X_{ALL}} = 2\,Q_M\,F_{RB} = 2\left[\frac{bh^2}{8}\right] F_{RB}, \qquad F_{RB} = 0.97\,F_{TU}$$

$$= 2\left[\frac{2.50\,(0.480)^2}{8}\right] 0.97 \times 58{,}000 = 8{,}100 \text{ In.-Lb}$$

$$M_{Y_{ALL}} = 2Q_M\,F_{RB} = 2\left[\frac{hb^2}{8}\right] F_{RB}$$

$$= 2\left[\frac{0.480\,(2.50)^2}{8}\right] 0.97 \times 58{,}000 = 42{,}200 \text{ In.-Lb}$$

$$P_{ALL} = F_{TU}\,A = F_{TU}\,bh = 58{,}000 \times 2.50 \times 0.480 = 69{,}500 \text{ Lb}$$

$$S_{X_{ALL}} = S_{Y_{ALL}} = F_{SU}\,A = F_{SU}\,bh = 35{,}000 \times 2.50 \times 0.480 = 42{,}000 \text{ Lb}$$

$$R_{BX} = \frac{M_X}{M_{X_{ALL}}} = \frac{6{,}450}{8{,}100} = 0.80, \qquad R_{BY} = \frac{M_Y}{M_{Y_{ALL}}} = \frac{11{,}400}{42{,}200} = 0.27$$

$$R_A = \frac{P}{P_{ALL}} = \frac{9{,}200}{69{,}500} = 0.13$$

$$\frac{R_A}{R_{BX}} = \frac{0.13}{0.80} = 0.16, \quad \frac{R_A}{R_{BY}} = \frac{0.13}{0.27} = 0.48,$$ The Smaller Value is Used to Determine M.S.

$$(M.S.)_{B+A} = \frac{R_{Xa}}{R_{BX}} - 1 = \frac{0.91}{0.80} - 1 = 0.14,$$ *Bending Plus Axial Load Only*

$$R_{S_X} = \frac{S_X}{S_{X_{ALL}}} = \frac{9,900}{42,000} = 0.24, \qquad R_{S_Y} = \frac{S_Y}{S_{Y_{ALL}}} = \frac{5,600}{42,000} = 0.13$$

$$(M.S.)_S = \frac{1}{\sqrt{R_{S_X}{}^2 + R_{S_Y}{}^2}} - 1 = \frac{1}{\sqrt{(0.24)^2 + (0.13)^2}} - 1 = 2.66, \text{ Shear Only}$$

$$U_N = \frac{1}{(M.S.)_{B+A} + 1} = \frac{1}{0.14 + 1} = 0.88$$

$$U_S = \frac{1}{(M.S.)_S + 1} = \frac{1}{2.66 + 1} = 0.27$$

$$M.S. = \frac{1}{\sqrt{U_S{}^2 + U_N{}^2}} - 1 = \frac{1}{\sqrt{(0.27)^2 + (0.88)^2}} - 1 = +\underline{\underline{0.08}}$$

LUG CHECK:

$$\frac{R}{D} = \frac{1.0}{0.5} = 2 \qquad P = 1.5 \times 6,130 = 9,200 \text{ Lb. Ult.}$$

$$\frac{D}{t} = \frac{0.50}{0.480} = 1.04$$

$K_{BRU} = 1.95$, Ref. (6) Page D1.7

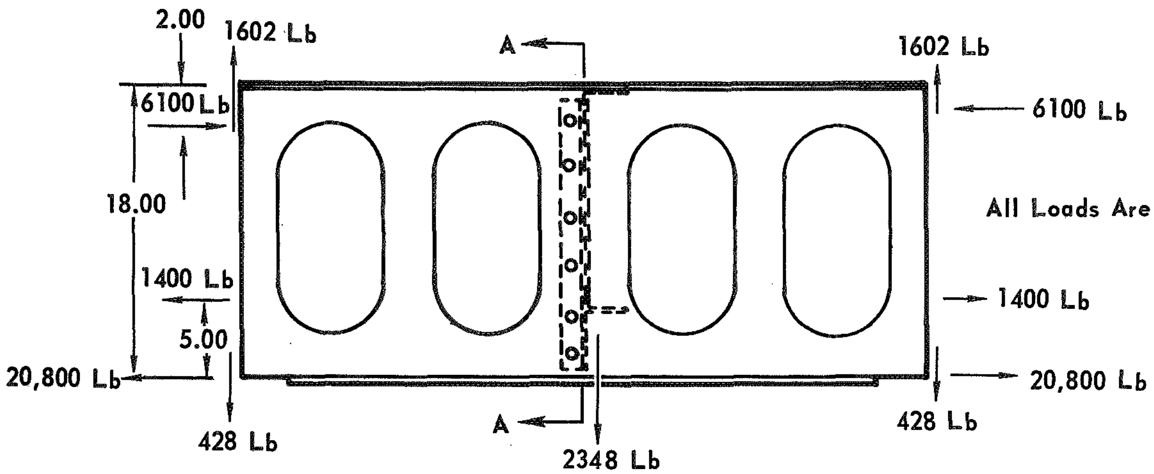
$P_{BRU} = K_{BRU}\, F_{TU}\, Dt = 1.95 \times 58,000 \times 0.5 \times 0.480 = 27,100$ Lb.

$$M.S. = \frac{P_{BRU}}{P} - 1 = \frac{27,100}{9,200} - 1 = +\underline{\underline{1.95}}$$

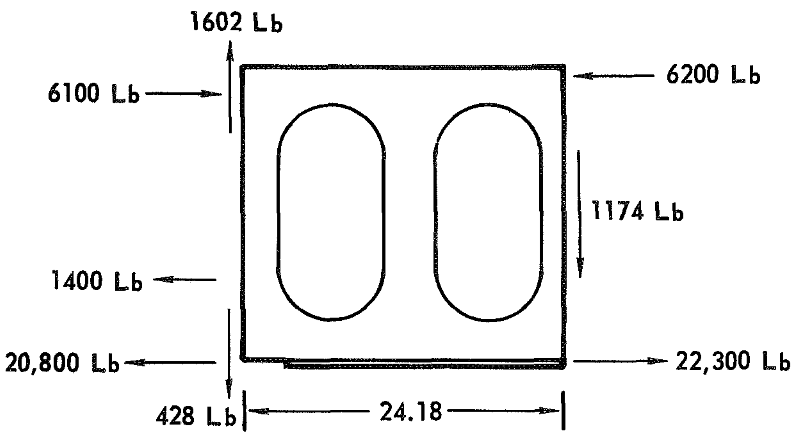
5.2.3 SIDE BEAMS

STRENGTH ANALYSIS – BEAM

Loading Condition (3) , Ref. Section 4.2.3

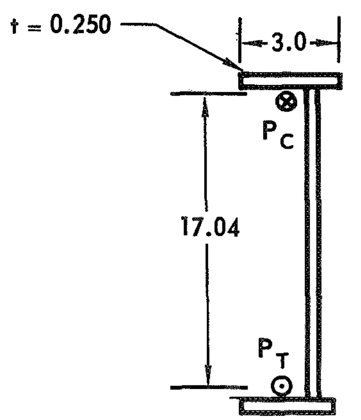


All Loads Are Limit



Material:
6061–T651 Al.
$F_{TU} = 42,000$ psi

BENDING CHECK OF SECTION A–A:



Section A–A

$P_T = 1.5 \times 22,300 = 33,500$ Lb Ult

$P_C = 1.5 \times 6200 = 9300$ Lb Ult

$A_T = A_C = 1.250 \text{ In.}^2$

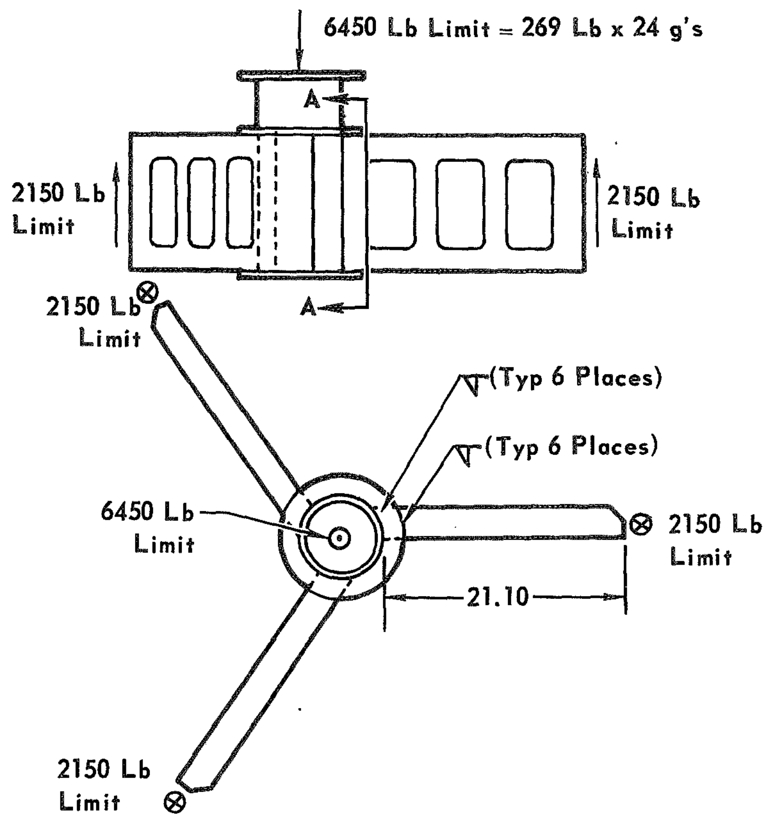
Section A–A is Tension Cap Critical

$P_{T_{ALL}} = F_{TU} A_T = 42,000 \times 1.250 = 52,500$ Lb

$$\text{M.S.} = \frac{P_{T_{ALL}}}{P_T} - 1 = \frac{52,500}{33,500} - 1 = +\underline{\underline{0.57}}$$

5.2.4 CENTER SECTION
STRENGTH ANALYSIS – RADIAL BEAM

Loading Condition (5), Ref. Section 4.2.4



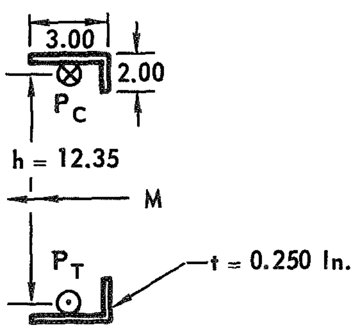
Concentrate Center Section and Ballast Weights at Center of Hub.

Center Section Wt	= 50.9 Lb
Ballast Wt	= 218.1 Lb
Total Wt	= 269 Lb

Material:
6061–T651 Al.
$F_{TU} = 42{,}000$ psi
$F_{CY} = 37{,}000$ psi
Weld
$F_{TU} = 18{,}000$ psi
$F_{TY} = 8000$ psi

BENDING CHECK OF SECTION A–A:

Section is Limit Load Critical



Section A–A

$$M = 2150 \times 21.10 = 45{,}300 \text{ In.-Lb Limit}$$

$$P_C = P_T = \frac{M}{h} = \frac{45{,}300}{12.35} = 3670 \text{ Lb Limit}$$

Tension Strength of Welds are Critical

$$P_{T_{ALL}} = F_{TY_{WELD}} A_{WELD} = 8000\ (5 \times 0.250) = 10{,}000 \text{ Lb}$$

$$M.S. = \frac{P_{T_{ALL}}}{P_T} - 1 = \frac{10{,}000}{3670} - 1 = \underline{\underline{+1.72}}$$

6. MASS PROPERTIES

The Landing Impact Test Model is designed to simulate the mass properties (weight, center of gravity, and moments of inertia) of the Mars legged lander. By the addition of ballast to the basic model, both full prototype mass properties and 3/8 prototype mass properties are simulated.

6.1 BASIC MODEL - Mass properties of the basic model were determined analytically using final engineering drawings and measured weights whenever possible. A detailed listing of weight, center of gravity, and radius of gyration for each item in the basic model is shown in Figure 6-1. The resulting mass properties of the basic model are summarized in Figure 6-2. All moments of inertia were determined with the landing gear in the fully extended position.

The coordinate system shown in Figure 3-1 was used. Its origin is on the ground plane and the X-axis extends vertically along the centerline of the vehicle. The radii of gyration shown in Figure 6-1 are defined in terms of the item's local coordinate system whose center is at the center of gravity of the item. Some items, such as center body structure and certain hardware, include a number of components symmetrically located about the X-axis. In these cases, the local coordinate system is located at the composite center of gravity of the components included.

As the manufacture of the model progressed, the individual components were weighed whenever possible. These values were incorporated in the mass property analysis. Approximately 90 percent of the basic model weight is based on measured values of individual components. In addition, the completed basic model and all ballast were weighed to verify total weight of both the

BASIC MODEL DETAIL PARTS BREAKDOWN

Item	Weight (Lb)	Center of Gravity (In.)			Radius of Gyration (In.)		
		X	Y	Z	K_X	K_Y	K_Z
Main Strut							
Cylinder	0.97	26.80	0.00	48.96	1.63	5.99	5.99
Cylinder	0.97	26.80	42.40	–24.98	1.63	5.99	5.99
Cylinder	0.97	26.80	–42.40	–24.98	1.63	5.99	5.99
Piston Rod	0.60	13.22	0.00	53.86	1.00	4.27	4.27
Piston Rod	0.60	13.22	46.55	–26.93	1.00	4.27	4.27
Piston Rod	0.60	13.22	–46.55	–26.93	1.00	4.27	4.27
Guide Tube	0.32	27.70	0.00	48.62	0.63	5.34	5.34
Guide Tube	0.32	27.70	42.00	–24.31	0.63	5.34	5.34
Guide Tube	0.32	27.70	–42.10	–24.31	0.63	5.34	5.34
Piston	0.50	20.20	0.00	51.36	1.07	0.84	0.84
Piston	0.50	20.20	44.40	–25.68	1.07	0.84	0.84
Piston	0.50	20.20	–44.40	–25.68	1.07	0.84	0.84
Screw	0.05	18.50	0.00	51.50	0.09	0.98	0.98
Screw	0.05	18.50	44.60	–25.75	0.09	0.98	0.98
Screw	0.05	18.50	–44.60	–25.75	0.09	0.98	0.98
Ring	0.50	17.53	0.00	52.30	1.28	0.79	0.79
Ring	0.50	17.53	45.50	–26.15	1.28	0.79	0.79
Ring	0.50	17.53	–45.50	–26.15	1.28	0.79	0.79
Clevis Fitting	0.44	6.00	0.00	56.40	0.56	1.30	1.30
Clevis Fitting	0.44	6.00	48.85	–28.20	0.56	1.30	1.30
Clevis Fitting	0.44	6.00	–48.85	–28.20	0.56	1.30	1.30
Lug	0.63	36.50	0.00	45.26	1.10	1.44	1.44
Lug	0.63	36.50	39.10	–22.63	1.10	1.44	1.44
Lug	0.63	36.50	–39.10	–22.63	1.10	1.44	1.44
Honeycomb	0.50	28.50	0.00	48.36	1.16	4.69	4.69
Honeycomb	0.50	28.50	41.90	–24.18	1.16	4.69	4.69
Honeycomb	0.50	28.50	–41.90	–24.18	1.16	4.69	4.69
Hardware	0.77	38.40	0.00	0.00	35.00	25.00	25.00
Footpad							
Footpad	2.75	2.63	0.00	57.00	4.60	3.25	3.25
Footpad	2.75	2.63	49.40	–28.50	4.60	3.25	3.25
Footpad	2.75	2.63	–49.40	–28.50	4.60	3.25	3.25
Trunnion	0.38	4.50	0.00	57.00	0.58	0.58	0.58
Trunnion	0.38	4.50	49.40	–28.50	0.58	0.58	0.58
Trunnion	0.38	4.50	–49.40	–28.50	0.58	0.58	0.58
Hardware	0.61	4.50	0.00	57.00	0.58	0.58	0.58
Hardware	0.61	4.50	49.40	–28.50	0.58	0.58	0.58
Hardware	0.61	4.50	–49.40	–28.50	0.58	0.58	0.58
Honeycomb	0.83	1.12	0.00	57.00	4.67	3.37	3.37
Honeycomb	0.83	1.12	49.40	–28.50	4.67	3.37	3.37
Honeycomb	0.83	1.12	–49.40	–28.50	4.67	3.37	3.37
A-Frame							
Tube	1.40	9.60	4.80	46.60	1.00	5.48	5.48
Tube	1.40	9.60	–4.80	46.60	1.00	5.48	5.48
Tube	1.40	9.60	37.75	–27.55	1.00	5.48	5.48
Tube	1.40	9.60	42.75	–19.05	1.00	5.48	5.48
Tube	1.40	9.60	–37.75	–27.55	1.00	5.48	5.48
Tube	1.40	9.60	–42.76	–19.05	1.00	5.48	5.48
Lug	1.01	13.70	9.25	36.90	1.06	1.53	1.53
Lug	1.01	13.70	–9.25	36.90	1.06	1.53	1.53
Lug	1.01	13.70	36.80	–10.50	1.06	1.53	1.53
Lug	1.01	13.70	27.50	–26.40	1.06	1.53	1.53
Lug	1.01	13.70	–36.80	–10.50	1.06	1.53	1.53
Lug	1.01	13.70	–27.50	–26.40	1.06	1.53	1.53
Apex Fitting	1.87	5.60	0.00	55.00	2.02	1.59	1.88
Apex Fitting	1.87	5.60	47.65	–27.50	2.02	1.59	1.88
Apex Fitting	1.87	5.60	–47.65	–27.50	2.02	1.59	1.88
Hardware	2.02	14.40	0.00	0.00	35.00	25.00	25.00
Center Body							
Side Beams, Center Section, Main Strut Support Beam and Interface	214.39	26.44	0.00	0.00	31.54	23.30	23.30
Interface Clevis	2.21	16.50	9.25	35.65	1.50	1.64	2.11
Interface Clevis	2.21	16.50	–9.25	35.65	1.50	1.64	2.11
Interface Clevis	2.21	16.50	26.20	–25.90	1.50	2.11	1.64
Interface Clevis	2.21	16.50	35.50	–9.75	1.50	2.11	1.64
Interface Clevis	2.21	16.50	–26.20	–25.90	1.50	2.11	1.64
Interface Clevis	2.21	16.50	–35.50	–9.75	1.50	2.11	1.64
Main Strut Clevis	0.82	38.37	0.00	44.00	1.30	1.44	1.44
Main Strut Clevis	0.82	38.37	38.00	–22.00	1.30	1.44	1.44
Main Strut Clevis	0.82	38.37	–38.00	–22.00	1.30	1.44	1.44
Hardware	2.29	18.00	0.00	0.00	37.00	26.00	26.00

FIGURE 6–1

BASIC MODEL MASS PROPERTIES

Weight (Lb)	Center of Gravity (In.)			Moments of Inertia (Slug-Ft^2)		
	X	Y	Z	I_{XX}	I_{YY}	I_{ZZ}
282.5	23.4	0	0	78.5	44.7	44.6

FIGURE 6–2

3/8 prototype mass model and the full prototype mass model. Items which were not individually weighed include the honeycomb elements for the footpads and main struts, hardware (nuts, bolts and rivets), and interface clevis fittings. These fittings received a finish machining operation during final assembly to achieve correct model geometry. All honeycomb elements are supplied by NASA Langley Research Center.

6.2 3/8 PROTOTYPE MASS - Mass properties for this version of the model are summarized in Figure 6-3. Also shown in parenthesis are the nominal values for mass properties specified in Reference (2).

The desired mass properties were achieved by adding two steel ballast rings and two small lead ballast plates to the basic model. Properties for these ballast pieces are given in Figure 6-4 and they are located on the basic model as given in Figure 6-5. Both ballast rings are attached to the cylindrical center section of the center body. One of the lead plates is attached to the interface structure on the positive Z-axis. The other plate is attached to the web of the radial beam on the minus Z-axis.

6.3 FULL PROTOTYPE MASS - Mass properties for this version of the model are given in Figure 6-6. Required nominal values (Reference 2) are shown also.

The mass properties were achieved by adding two steel rings and nine lead bars to the basic model. Properties for these items are shown in Figure 6-7. They are located on the model as shown in Figure 6-8. The steel rings are attached to the cylindrical center section and the lead bars are strategically located on side beams and interface structure of the center body.

MASS PROPERTIES
FOR
3/8 PROTOTYPE MASS MODEL

Item	Weight (Lb)	Center of Gravity (In.)			Moments of Inertia About Target CG (Slug-Ft^2)		
		X	Y	Z	I_{XX}	I_{YY}	I_{ZZ}
Basic Model	282.5	23.4	0	0	78.5	45.0	44.9
Ballast	137.5	29.9	0	0	1.9	5.7	4.7
Total	420.0	*25.6	0	0	80.4	50.7	49.6
Nominal Goals	(420.0)	(25.6)	(0)	(0)	(78.0)	(53.0)	(48.0)

*Target CG

FIGURE 6–3

BALLAST PROPERTIES FOR 3/8 PROTOTYPE MASS MODEL

Item	Weight (Lb)	Center of Gravity (In.)			Radius of Gyration (In.)		
		X	Y	Z	K_X	K_Y	K_Z
Ring 1	56.7	43.0	0	0	5.89	4.22	4.22
Ring 2	75.8	20.5	0	0	5.68	4.05	4.05
Plate 1	2.85	26.2	0.3	−26.0	0.9	1.47	1.18
Plate 2	2.15	26.2	0	34.5	1.18	0.9	1.47
Totals	137.5	29.9	0	0	8.01	12.97	11.67

FIGURE 6–4

BALLAST LOCATIONS FOR 3/8 PROTOTYPE MASS MODEL

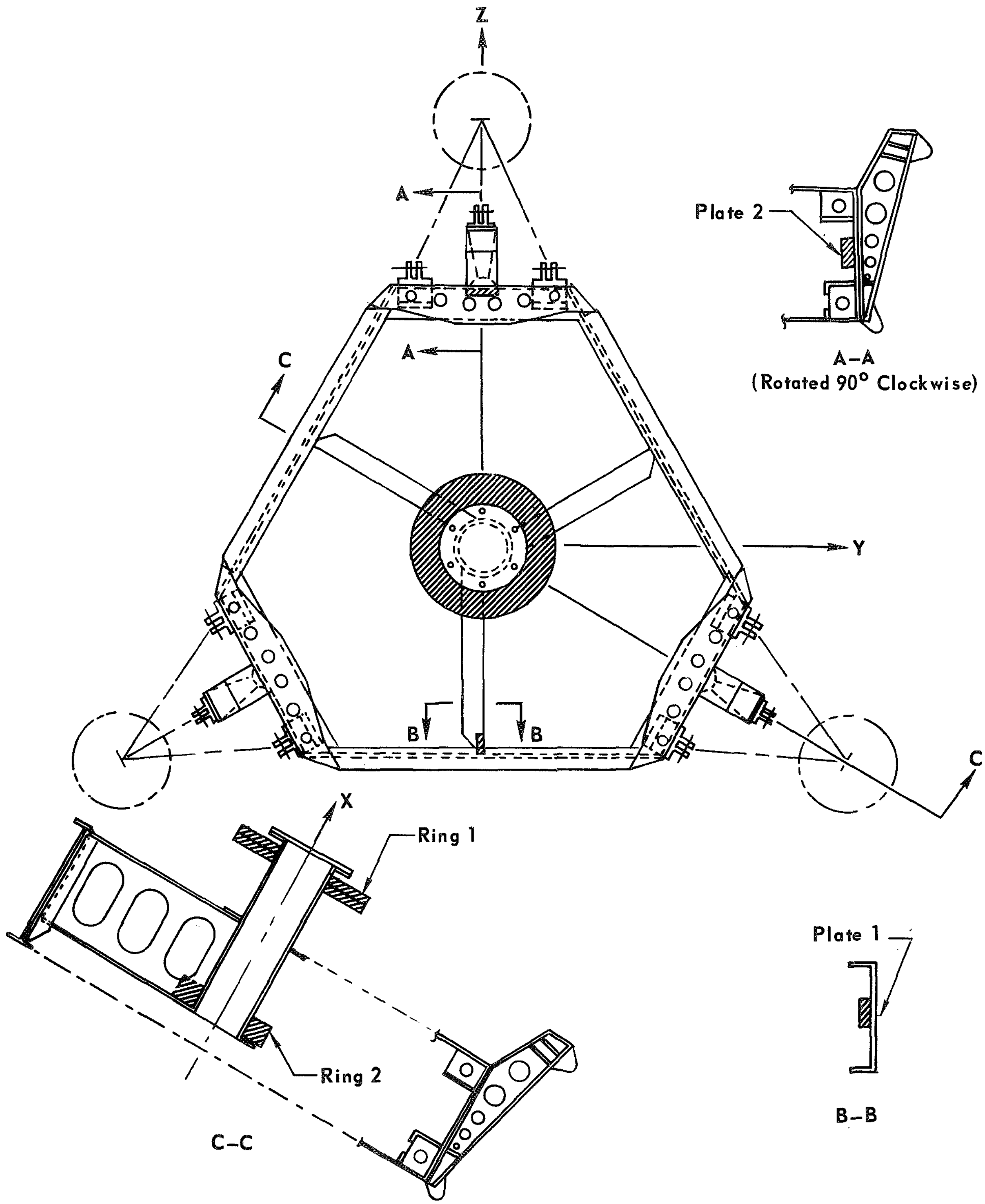


FIGURE 6–5

MASS PROPERTIES FOR FULL PROTOTYPE MASS MODEL

Item	Weight (Lb)	Center of Gravity (In.)			Moments of Inertia About Target C.G. (Slug-Ft^2)		
		X	Y	Z	I_{XX}	I_{YY}	I_{ZZ}
Basic Model	282.5	23.4	0	0	78.5	45.0	44.9
Ballast	844.5	26.3	0	0	136.5	95.8	78.4
Total	1127.0	*25.6	0	0	215.0	140.8	123.3
Nominal Goals	(1127.0)	(25.6)	0	0	(208.0)	(142.0)	(128.0)

* Target C.G.

FIGURE 6-6

BALLAST PROPERTIES
FOR
FULL PROTOTYPE MASS MODEL

Item	Weight (Lb)	Center of Gravity (In.)			Radius of Gyration (In.)		
		X	Y	Z	K_X	K_Y	K_Z
Ring 1	139.7	43.0	0	0	7.48	5.34	5.34
Ring 2	78.4	21.0	0	0.	5.65	4.08	4.08
Bar 1	63.0	34.4	24.3	14.2	6.24	5.58	3.75
Bar 2	63.0	34.4	-24.3	14.2	6.24	5.58	3.75
Bar 3	107.8	16.8	24.8	14.4	12.14	10.58	6.47
Bar 4	107.8	16.8	-24.8	14.4	12.14	10.58	6.47
Bar 5	78.5	18.6	14.9	-29.3	3.06	2.17	3.52
Bar 6	78.5	18.6	-14.9	-29.3	3.06	2.17	3.52
Bar 7	37.1	34.4	14.9	-28.4	3.06	1.27	3.12
Bar 8	37.1	34.4	-14.9	-28.4	3.06	1.27	3.12
Bar 9	53.6	21.5	0	33.4	3.55	1.39	3.64
Totals	844.5	26.3	0	0	27.33	22.91	20.71

FIGURE 6-7

BALLAST LOCATIONS FOR FULL PROTOTYPE MASS MODEL

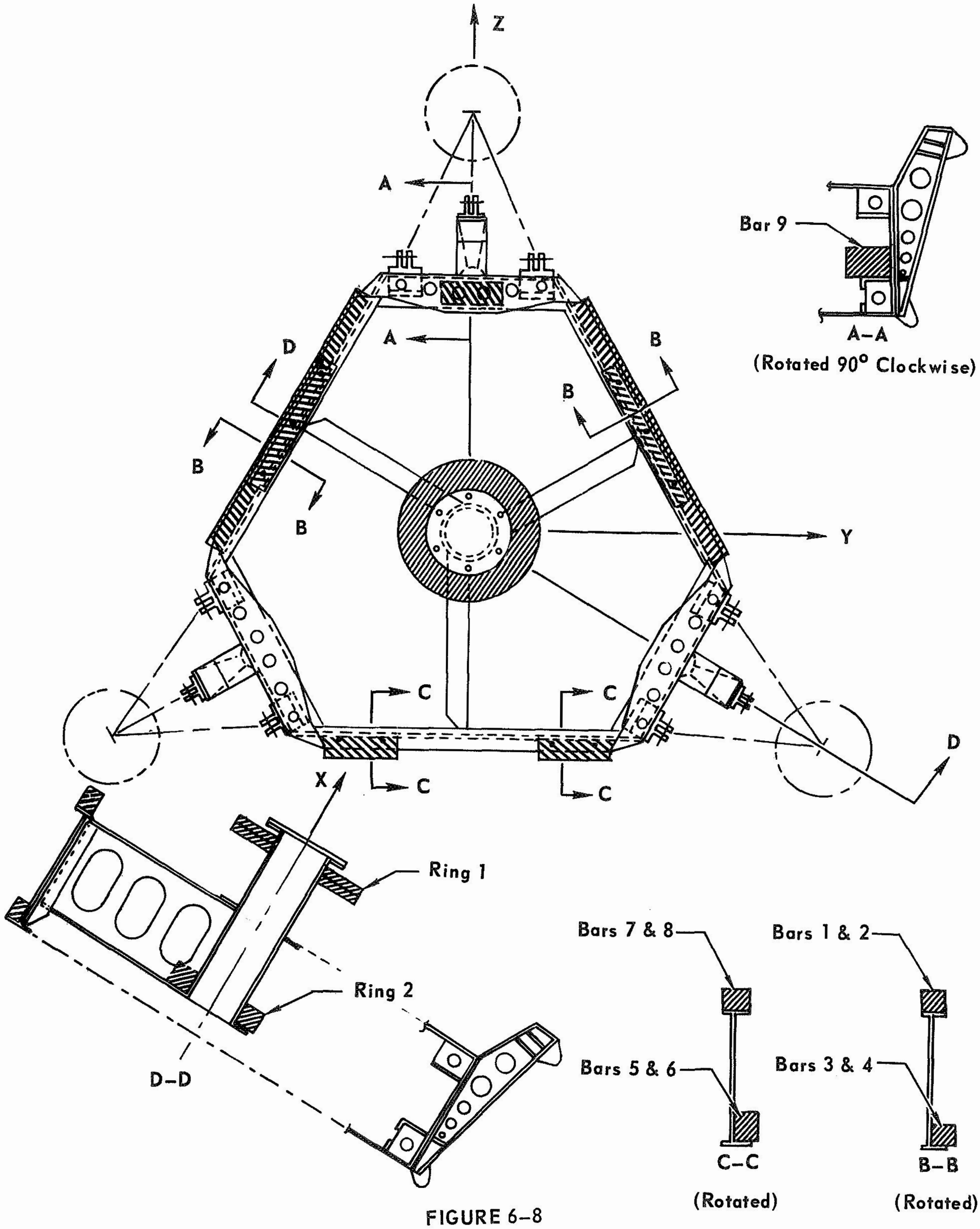


FIGURE 6–8

7. CONCLUSIONS

The structural adequacy of the landing impact test model has been analytically verified in this report. The model geometry, weight, center of gravity location and moments of inertia are within constraints specified by NASA Langley Research Center. Minimum margins of safety and model mass properties are summarized in Section 1.0.

8. REFERENCES

1. Statement of Work for Task Order Three, "Design and Fabrication of a Full-Size Landing Impact Test Model of the Mars Legged Lander Configuration" of Master Agreement Contract NAS 1-8137, "Analysis, Design, and Fabrication of Landing Impact Test Vehicles for Unmanned Planetary Landing," National Aeronautics and Space Administration, Langley Research Center, Hampton, Virginia, September 15, 1969.

2. Addendum Number Two to RFP, TWX from National Aeronautics and Space Administration, Langley Research Center, Hampton, Virginia, October 6, 1969.

3. MIL-HDBK 5A, "Metallic Materials and Elements for Aerospace Vehicle Structures," Revised Edition, February 8, 1966.

4. Peery, D. J., "Aircraft Structures," McGraw-Hill Book Company, Inc., New York, 1950.

5. Roark, R. J., "Formulas For Stress and Strain," McGraw-Hill Book Company, Inc., New York, 1954.

6. Bruhn, E. F., "Analysis and Design of Flight Vehicle Structures," Tri-State Offset Co., Cincinnati, Ohio, 1965.

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons.

CONTRACTOR REPORTS: Scientific and technical information generated under a NASA contract or grant and considered an important contribution to existing knowledge.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities. Publications include conference proceedings, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

TECHNOLOGY UTILIZATION PUBLICATIONS: Information on technology used by NASA that may be of particular interest in commercial and other non-aerospace applications. Publications include Tech Briefs, Technology Utilization Reports and Notes and Technology Surveys.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION DIVISION
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D.C. 20546